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STATUS OF LOBSTER STOCKS IN THE NORTHWESTERN HAWAIIAN ISLANDS, 1998-2000

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INTRODUCTION

The status of the Northwestern Hawaiian Islands (NWHI) lobster stocks has been assessed by the National Marine Fisheries Service, Honolulu Laboratory (NMFS-HL) since 1983. This report describes the status of lobster stocks in the NWHI, summarizes the results of research conducted from 1998 through 2000 to determine stock status, and discusses recent developments in the fishery.

Before proceeding, a number of terms referred to in this report need to be defined. Exploitable population is the total number of lobsters including both Hawaiian spiny lobster (*Panulirus marginatus*) and slipper lobster (*Scyllarides squammosus*) of both sexes that are vulnerable to the commercial fishing gear. Mature spiny and slipper lobsters are those lobsters $\geq$ 50 mm tail width (TW) and $\geq$ 56 mm TW, respectively. Immature spiny and slipper lobsters are those that are < 50 mm TW and < 56 mm TW, respectively. Berried lobsters (spiny or slipper lobster) are those carrying extruded eggs. Catch-per-unit-effort (CPUE) is the catch associated with a single trap haul and landings-per-unit-effort (LPUE) is the number of lobsters within a single trap haul that are retained and landed.

Ecological Dynamics

The NWHI ecosystem is highly fragmented and consists of a series of isolated islands, banks, atolls, islets, and reefs (hereafter referred to as banks) which extend 1,500 nmi west-northwest of the main Hawaiian Islands (Fig.1). The NWHI lie near the center of the Subtropical Gyre, and a weak geostrophic current flows along the NWHI from northwest to southeast. The amount of lobster habitat (defined as the area between 10 and 30 fm) varies between banks, ranging from 15 to 589 mi^2, and at any particular bank the available habitat is generally patchy.

There is considerable overlap in the range of depths at which spiny lobster and slipper lobster are found in the NWHI. Spiny lobster are found at depths ranging from 5-40 fm with highest concentrations occurring between 15 and 25 fm (Uchida and Tagami, 1984). Slipper lobster inhabit deeper waters ranging from 15-60 fm with highest concentrations occurring between 25 and 35 fm. The reason for the apparent separation is unknown but may be because of competition for available habitat. In recent years slipper lobster concentrations in shallow areas (15-25 fm) have increased as the concentrations of spiny lobster have decreased.

Research data collected prior to significant commercial fishing documented asynchronous dynamics among bank-specific populations of spiny lobster (Uchida et al., 1980a; Uchida et al., 1980b; Uchida and Tagami, 1984). The average size of spiny lobsters generally increased northwestward from Nihoa along the Hawaiian Archipelago (Uchida et al., 1980b). While spiny lobster are distributed throughout the entire NWHI, the highest densities (based on research survey CPUE) were found at Necker Island and Maro Reef, followed by Gardner Pinnacles, Raita Bank, and Laysan Island (Uchida et al., 1980a). Other banks surveyed included Nihoa, French Frigate Shoals, St. Rogatien, Pioneer, Lisianski Island, Pearl and Hermes Reef, Midway Islands, and Kure Atoll, all of which exhibited lower densities. One interesting result of the early survey work is the apparent lack of a relationship between bank habitat (area between 10 and 30 fms) and spiny lobster relative abundance ($p > 0.05$) (DiNardo et al., 1998).

Because of the protracted pelagic larval phase of NWHI spiny lobster (11-12 months) and slipper lobster (3-4 months) recruitment to a bank is likely dependent, in part, on lobster reproduction at surrounding banks: populations inhabiting discrete bank populations are connected by the dispersal of larvae between banks. This results in banks acting as either recruitment sources, sinks, or both. Historical research survey data collected prior to any significant increase in anthropogenic activities in the NWHI suggest that the region between Necker Island and Maro Reef is a major sink area for spiny lobster larvae (Uchida et al., 1980b). The ratio of legal (≥ 77 mm carapace length) to sublegal (< 77 mm carapace length) spiny lobster in the catch from Necker Island, French Frigate Shoals, Maro Reef, and Gardner Pinnacles was significantly lower compared to other banks in the NWHI. Banks northwest of Maro Reef exhibited the highest ratios, implying lower, or even sporadic, levels of recruitment. In most cases more than 90% of the total catch of spiny lobster on these banks was legal sized. Populations with low or sporadic recruitment are less resilient and very susceptible to depletion and overfishing.

DATA SOURCES

In this section, resource monitoring and research conducted by the NMFS-HL to support NWHI lobster stock assessments are described. The availability and quality of the collected data (e.g., catch, population size structure, etc.) are summarized and presented as information matrices. It should be noted that despite almost 20 years of monitoring and research directed at NWHI lobster stocks, information to support stock assessments is scant.

Information Matrices

The availability and quality of data collected by the various NWHI lobster monitoring programs are presented in Tables 1 and 2. Four subjective categories describing the quality of data are defined. Blanks in the matrices indicate no data. Open circles indicate poor data with high uncertainty, no corroborative analyses, and low frequency (only 1-3 years of data available). Half filled circles indicate moderate data with moderate uncertainties, anecdotal corroborative evidence, and moderate frequency (4-6 years of data). Filled circles indicate good data with low uncertainties, corroborative analyses, and sufficient time series (> 6 years of data).

The temporal extent of data for the NWHI (pooled across all banks) is depicted in Table 1, while the spatial extent of the data (at the bank level) is depicted in Table 2. Prior to 1995, there is a general paucity of data to advance stock assessments, and previous assessments relied solely on commercial catch and effort data. Since 1995, monitoring of both the fishery and lobster populations has increased significantly in an effort to provide necessary data to advance population model development and stock assessments.

The majority of fishery-dependent data are collected by logbooks. Fishery size composition data are collected through a voluntary observer program established in 1997 and recent fishery performance data collected as part of the tagging experiments.

One obvious deficiency with the fishery-independent monitoring programs is the general lack of spatial resolution. Resource monitoring programs have generally been limited to Necker Island and Maro Reef, which in recent years has received the majority of fishing effort. Scant data are available from other banks, not enough to allow estimates of stock size. While it is important to monitor the population in areas fished, it is paramount to monitor the entire population, especially when the local populations (banks) are dependent on one another. Future fishery-independent sampling should be more cognizant of this need.

Fishery-Dependent Information

NMFS Daily Lobster Catch Report

The NWHI lobster trap fishery, which commenced in the mid-1970s, is a multispecies fishery and primarily targets the Hawaiian spiny lobster and slipper lobster. Three other species, green spiny lobster (*P. penicillatus*), ridgeback slipper lobster (*S. haanii*), and Chinese slipper lobster (*Parribacus antarcticus*) are caught in low abundance. To provide fishery information for stock assessment and management purposes vessel captains have been required under Amendment 1 of the Crustaceans Fishery Management Plan (FMP) to submit a trip logbook with data on daily catch (in numbers), lobsters retained (landings), fishing effort (number of traps hauled), and area fished (bank) providing an 18-year time series (1983-2000). Fishery statistics during the early developmental phase of the fishery (1976-82), prior to the establishment of the Crustaceans FMP, are scant. Also, despite significant changes in trap configuration during the 1980s, information identifying the type of trap fished is not available.

Catch Size Composition Sampling

Size composition data from the commercial catch have been routinely collected by biological technicians aboard commercial fishing vessels only since 1997. Approximately 50 lobsters are randomly selected from the catch of each trap string; for each sampled lobster, tail width and reproductive condition are recorded. The biological technicians also reported on daily fishing, sorting, and discard methods.

Prior to 1997, size composition data are scant and not representative of the commercial catch. The lack of historical size composition data precludes our ability to monitor changes in size composition over time, especially during the various developmental phases (e.g., growth, fully-exploited, etc.) of the NWHI commercial lobster fishery.

Fishery-Independent Information

Honolulu Laboratory Annual NWHI Lobster Survey

A fishery-independent trap survey was conducted annually from 1984 to 1989 and 1991 to 2000 by the NMFS-HL to (1) evaluate the performance of commercial and research survey gear, (2) calibrate gear types, and (3) monitor local populations of lobster in the NWHI. The survey has also been used as a platform for short-term experiments (e.g., studies of handling mortality) and the collection of biological and oceanographic data.

The survey uses a fixed-site design stratified by depth, and at each site shallow (< 20 fm) and deep (≥ 20 fm) stations are sampled. Ten strings of eight traps each are set at the shallow station and two to four strings of 20 traps each are set at the deep station. Traps are fished overnight and baited with 1.5-2.0 pounds of cut-up, previously frozen, mackerel. Data on species, tail width, sex, and reproductive condition (berried or unberried) are collected for each lobster caught, as well as the latitude and longitude of the traps recorded at the string level. The geographical extent of the trap survey has generally been limited to Necker Island and Maro Reef, with infrequent trips to adjacent banks.

Between 1984 and 1991 a variety of gears and gear configurations were used in the research survey. California two-chambered wire lobster traps (hereafter referred to as California trap) were used from 1985 to 1991. Fathom Plus® black polyethylene plastic traps (hereafter referred to as black plastic trap), without escape vents, were first used in 1984, and since 1992 they have been used exclusively in the survey. While trap comparison studies were conducted to provide a conversion formula for California trap and black plastic trap CPUE, the studies were incomplete. Thus in computing CPUE from research survey data we are limited to years in which black plastic traps were fished in significant numbers at both shallow and deep stations (≥ 50% of the total traps fished). For Maro Reef this corresponds to years 1987-2000 and for Necker Island years, 1988-2000.

Population Size Composition Sampling

Since the mid-1980s lobster size composition sampling has been routinely conducted at Necker Island and Maro Reef during the NWHI fishery-independent trap survey. Because a variety of research gears, each having a different selectivity pattern, were fished throughout the 1980s, size composition samples from these surveys may not be representative of the population. Added to the problems associated with changing selectivity patterns is the fact that up until 1997 the spatial distribution of sampling at Necker Island was not random with respect to the distribution of lobsters at Necker Island. Sampling was generally limited to habitat for juvenile spiny lobster, and areas not sampled contained higher proportions of larger spiny lobsters (DiNardo, 1997). Thus, despite 16 years of size composition sampling at Necker Island only those data collected after 1996 could be considered representative of the local lobster population.

NMFS/Industry Cooperative Research

Lobster Tagging Studies

During a recent technical review of the NWHI lobster assessment models it was recommended that collaborative research programs between industry and the NMFS-HL be developed to provide independent estimates of population size and updated estimates of population dynamics and fishing parameters. In accordance with these recommendations the NMFS-HL lobster research team, with wide support from industry, developed and implemented a NWHI lobster tagging program in 1998. Insufficient funds, however, prematurely terminated the program after only 1 year.

Tagging cruises were conducted at Necker Island during September 1998 and March and June 1999; the 1999 NWHI commercial lobster fishery provided the platform for recaptures. Approximately 6,000 spiny lobster were tagged and released at Necker Island, and about 320 tagged spiny lobster were recaptured during the 1999 commercial lobster fishery (Fig. 2). Biological technicians examined all decked lobsters for tags and recorded the necessary information.

COMMERCIAL CATCH AND EFFORT HISTORY

Catch, Effort, and Targeting

The total reported catch and landings of lobsters peaked in 1985 at approximately 2,736,000 and 2,031,000 lobsters, respectively, and generally declined from 1986 to 1995 (Table 3; Fig. 3). Fishing effort peaked in 1986 at approximately 1,290,000 trap hauls and declined to 834,000 trap hauls in 1988 before increasing to 1,180,000 trap hauls in 1990. After 1990 fishing effort generally declined.

The fishery initially targeted spiny lobster, but by 1985 gear modifications and improved markets led to an increase in slipper lobster landings. Catches of slipper lobster remained high from 1985 to 1987, fell into a general decline from 1988 to 1996, and increased significantly from 1997 to 1999 (Fig. 4).

The proportion of fishing effort and reported catch at each bank within the NWHI has varied both spatially and temporally. While as many as 16 banks within the NWHI were fished on an annual basis, the majority of fishing effort has been directed at 4 banks: Maro Reef, Gardner Pinnacles, St. Rogatien, and Necker Island (Fig. 5). Between 1984 and 1989 most of the fishing effort was directed at Maro Reef. After 1989, fishing effort decreased at Maro Reef and increased significantly at Gardner Pinnacles and Necker Island. In 1996 and 1997, the majority of fishing effort was directed at Necker Island. Spatial management commenced in 1998, redistributing fishing effort throughout the archipelago.

In general, the observed spatiotemporal shifts in fishing effort between banks are attributed to declines in spiny lobster CPUE; as spiny lobsters were fished down and catch rates at a particular bank fell below some minimum economic threshold, fishing effort shifted to more productive banks. By the mid 1990s fishing was generally limited to Necker Island where relatively higher concentrations of spiny lobsters were found. With the adoption of spatial management in 1998 fishing effort was redistributed throughout the NWHI and the major target of the fishery changed to slipper lobster.

Fishing Gear and Fishing Practices

In the three years of concentrated growth occurring between 1983 and 1986, the NWHI lobster fishery developed from a modest live-lobster, home-market operation into a multispecies operation exporting live and frozen tails internationally (Clarke et al., 1992). Associated with the fisheries growth was a transition in commercial fishing gear, vessel size, fleet participation, and number of traps fished. The period during 1984-85 marked the transition between the use of the California trap and the black plastic trap. Intensity of fishing effort, catch composition, and catch rates were strongly influenced by this change in gear type. In addition, deck space constraints, which had restricted the number of California traps carried by each vessel, eased with the introduction of the much more compact black plastic trap. The resulting increase in trap carrying capacity, in turn, contributed to an immediate rise in fishing effort and fishing mortality (Gates and Samples, 1986).

The basic California trap is rectangular and is constructed with heavy gauge galvanized wire. It measures 92 cm in length by 71.5 cm in width and 41 cm in height and has an open mesh 4.7 cm long by 9.7 cm wide. A number of field modifications were made to the basic design in attempts to modify the fishing characteristics and catch rates of this trap. This included sheathing the trap with finer mesh, enlarging the entrance cones, coating the wire with plastic of various colors, and reducing the mesh size of the bait container (Clarke and Sumida, unpublished report). The effects of these modifications on commercial catch rates are unknown.

The California traps were effective at catching spiny lobster, relatively ineffective at catching slipper lobster, and were typically fished in strings of between 75 and 150 traps. On average, 400 traps would be hauled, baited, and reset daily by each vessel (Clarke and Sumida, unpublished report).

Use of the California trap declined with the introduction of the black plastic trap. Although not outright discarded, California traps lost or damaged at sea were readily replaced by the inexpensive, portable, and more efficient black plastic trap (Ray Clarke, pers. commun.). By 1985, only 1 year after its introduction, 90% of all traps fished were of the black plastic design (Clarke and Sumida, unpublished report).

The basic shape of the black plastic trap has changed little since its introduction. It is oval, slightly tapered towards the top, and is domed at the center. Plate steel or cast lead ballast is bolted, wired, or banded to the base of each trap half.

A significant modification was made to the basic design of the black plastic trap in late 1985. Eager to market a trap for the deep water shrimp fisheries developing in Hawaii and along the west coast of the U.S., the manufacturer of the black plastic trap added vertical rungs in the existing trap mesh (Ray Clarke, pers. commun.). This reduced the open mesh area from 4.5 cm by 4.5 cm to 2 cm by 4.5 cm across the top, 1.6 cm by 4.3 cm across the front (bridle end), 1.8 cm by 4.5 cm across the sides, and between 1.3 cm by 4 cm and 1.3 cm by 4.5 cm across the rear. As a result, the trap mesh of the current black plastic trap is between 56 and 74 % less than the early version of the same trap and 80 to 89 % less than the California wire trap. The effect of the reduced mesh size on lobster populations cannot be assessed because historical size structure data was not available from the NWHI commercial lobster fishery. However, reduced mesh size likely contributed to the reported increase in sublegal lobster catch rates, which in turn, resulted in increased discard and fishing mortality.

Contrasting with the bulky and rigid California trap, the most significant feature of the black plastic trap is its ability to be broken down and nested compactly for transport. This increased portability led to a pronounced increase in the number of traps carried by each vessel, which in turn, dramatically amplified the fishing potential of the fleet as a whole (Gates and Samples, 1986). Complementing this was a trend toward larger vessels, embarking on more frequent and longer trips (Gates and Samples, 1986). Boats could now easily carry 800-1,200 traps, and the average number of traps fished daily increased from 400 traps to 1,000 traps.

As early as 1980, problems with high catch rates of small immature lobsters and associated discard mortality were identified (MacDonald and Stimson, 1980). The requirement for traps to include escape vents was adopted in 1987 and implemented in 1988. From 1983 through 1995 the lobster (spiny lobster and slipper lobster combined) discard rate (the reported ratio of lobsters discarded to total lobsters caught) generally increased, rising from 0.28 in 1983 to 0.62 in 1995 (Fig. 6). After 1995, the discard rate decreased significantly as a result of a relaxation of the minimum legal size requirement in favor of an optional retain-all policy. Gear changes (introduction of black plastic trap and reduction in trap mesh size) and spatiotemporal shifts in fishing effort contributed to the reported increase in discard rate between 1983 and 1995.

Recent Developments

The 1998 and 1999 NWHI commercial lobster fisheries have previously been described by Kawamoto and Pooley (2000; in prep). The major development in the 1998 lobster fishery was the adoption of a spatial management regime requiring area-specific estimates of exploitable population. Spatial management continued in 1999 and area-specific estimates of exploitable population were again computed. The fishery was closed in 2000 due to increasing uncertainty in the population models used to assess stock status. In December 2000 President Clinton, through Executive Order (EO) 13178 and later through EO 13196, established the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve which may prohibit commercial lobster fishing in the NWHI for at least 10 years.

INDICES OF ABUNDANCE

Fishery-Dependent Indices

Commercial lobster LPUE (pooled across all banks) declined from 2.75 lobsters/trap haul in 1983 to 0.98 lobsters/trap haul in 1987 and then increased to 1.26 lobsters/trap haul in 1988 before declining to an average of 0.63 lobsters/trap haul between 1991 and 1995 (Fig. 7). LPUE increased to an average of 1.68 lobsters/trap haul between 1996 and 1997 before declining to 1.0 lobsters/trap in 1999. This sudden increase in reported LPUE during the 1996 and 1997 fishing seasons resulted from changes in management policies and fishing strategies and not significant increases in the population. The 1996 and 1997 commercial fisheries operated under the guidelines of Amendment 9 which allowed all lobsters caught and decked to be landed (eliminated regulatory discards). Also, most of the fishing effort in 1996 and 1997 was directed at Necker Island, the most productive bank. In addition, areas with higher concentrations of slipper lobster were specifically targeted by some participants during the 1997-99 commercial fishery, representing a change in fishing strategy. In previous years minimum size limits were imposed and fishing occurred on several banks, including less productive banks. The drop in LPUE during the 1998 and 1999 fishing seasons resulted from the adoption of spatial management which redistributed fishing effort throughout the NWHI. Reevaluating the 1996-97 and 1998-99 LPUEs by assuming historical minimum legal sizes resulted in hypothetical average LPUEs of 1.21 and 0.91, respectively.

The reported LPUE time series, from banks in which at least 5 years of commercial fishing data are available, all exhibit similar declining trends (Fig. 8). For many of the banks a 50% drop in LPUE was reported between 1983 and 1987. Data are insufficient to assess specific causes for the observed declines in NWHI lobster LPUEs, but fishing mortality is a likely contributor. Significant increases in lobster LPUEs were observed at some banks in 1997 and 1998 resulting from a switch in target species of spiny lobster to slipper lobster.

Fishery-Independent Indices

Since 1990 Necker Island spiny lobster research CPUEs have generally decreased (Fig. 9). Significant drops in CPUE were observed in 1992, 1994, and 1998. Slipper lobster research CPUEs have remained at relatively low levels at Necker Island between 1988 and 2000.

Spiny lobster research CPUEs at Maro Reef declined significantly after 1988 and have since remained low (Fig. 10). Slipper lobster CPUEs at Maro Reef have generally been increasing, with significant increases occurring after 1991. These changes suggest a switch in species dominance at Maro Reef, an increase in slipper lobster as spiny lobster were fished down and habitat became available to slippers.

Factors Affecting Abundance

Research to date has identified a dynamic change in the spatial and temporal structure of the NWHI lobster population. Based on oceanographic research, size class and genetic structure analysis, and CPUE trends it appears that recruitment in the NWHI spiny lobster population differs between the southeastern and northwestern segments of the archipelago and remains low in the northwestern segment relative to the 1975-85 level. Numerous hypotheses have been advanced to explain population fluctuations of lobsters in the NWHI including environmental (Polovina and Mitchum, 1992), biotic (e.g., habitat and competition) (Parrish and Polovina, 1994), and anthropogenic (e.g., fishing) (Polovina et al., 1995). Each hypothesis by itself offers a plausible, however simplistic, explanation of events that in fact result from several processes acting together. It is likely that population fluctuations of lobsters in the NWHI can be more accurately described by a mix of the hypotheses presented, each describing a different set of mechanisms.

MODELS OF POPULATION DYNAMICS

Spatial management commenced in 1998 requiring estimates of exploitable population for each of the four management areas (Necker Island, Maro Reef, Gardner Pinnacles, and all remaining banks) in the NWHI. Area-specific estimates of the exploitable populations of lobsters in the NWHI are computed using a variety of methods. Exploitable populations at Necker Island (N_{NI}) and Maro Reef (N_{MR}) are computed using a two-step process. In step one, monthly commercial lobster catch and effort data from 1983 to the present are used to fit a discrete population model (Haight and Polovina, 1993), and estimates of the catchability coefficient (q), recruitment (R), and the initial exploitable population size (N_1) are computed. The model states that the number of exploitable lobsters at the beginning of a month is equal to the number of lobsters at the start of the previous month, minus natural mortality and catch during the previous month, plus the month's recruitment:

$$\begin{aligned} N_{i+1} &= N_i - (N_i(1-S) - C_i + R/12 \\ &= N_iS - C_i + R/12, \end{aligned} \tag{1}$$

where N_i is the population size at the beginning of month i, S is the monthly survival rate in the absence of fishing, C_i is the catch during month i, and R is the annual recruitment to the exploitable stock. The annual instantaneous natural mortality currently used for NWHI lobster stock assessment and population modeling is 0.456. The estimate was obtained by fitting a discrete population model to pooled (species and areas) monthly commercial CPUE data from 1983 through 1992 (Haight and Polovina, 1993).

It is assumed that the average CPUE during a month is proportional to lobster abundance at the beginning of the month:

$$\mathrm{CPUE}_i = qN_i, \tag{2}$$

allowing the model of population dynamics to be reexpressed in terms of CPUE as:

$$\mathrm{CPUE}_{i+1}/q = (\mathrm{CPUE}_i/q)S - C_i + \mathrm{R}/12. \qquad (3)$$

As described by Haight and Polovina (1993), the model parameters are estimated by fitting this equation to monthly statistics on CPUE and catch using least-squares methods.

In step two, a forecast of the relative abundance (CPUE) of lobsters at the start of the next fishing season (July 1) is computed from the model and, based on an assumed relationship between population size and relative abundance ($N_i = \mathrm{CPUE}_i/q$), the exploitable population of lobsters is estimated.

NWHI lobster population models assume 2-stanza constant recruitment: recruitment is constant at one level, R_1, from 1983 through October 1989, and at a different level, R_2, from November 1989 onward. Haight and Polovina (1993) fit a discrete population model to commercial CPUE data from 1983 through 1992 and found that the model fit quite well through 1989, but tended to overestimate observed CPUE after 1989. Based on oceanographic and population studies by Polovina and Mitchum (1992), Haight and Polovina (1993) attributed the poor fit of the model after 1989 to a change in recruitment. They rejected alternative hypotheses that the catchability had declined or natural mortality had increased. Subsequently, they fit the model to the same CPUE data assuming a two-phase recruitment: a high value that prevailed through October 1989, and a lower value thereafter. This more elaborate model fit the data much better.

Because catch and effort data from Gardner Pinnacles are scant, particularly in recent years, a discrete population model cannot be estimated. Instead, a forecast of the exploitable population on July 1 is computed as (CPUE_{L95} / q) where CPUE_{L95} is the lower 95% confidence limit for average commercial CPUE at Gardner Pinnacles from 1992 to the present, and q is the catchability coefficient at Necker Island.

Exploitable population in the fourth management area is computed as:

$$N_{OTHER} = N_{NWHI} - N_{NI} - N_{MR} - N_{GP} \qquad (4)$$

where N_{OTHER} = the estimated number of exploitable lobsters at all remaining banks and N_{NWHI} = the estimated number of exploitable lobsters in the entire NWHI. The estimate of N_{NWHI} is computed by applying the two-step process described for Necker Island and Maro Reef to commercial catch and effort data pooled over the entire archipelago.

There are six assumptions associated with the procedures outlined above including (1) homogeneous population dynamics between banks in the NWHI; (2) 2-stanza constant recruitment: recruitment was constant at one level, R_1, up to time t (October 1989), then changed to a second constant level, R_2; (3) natural mortality is constant and equal to 0.456^{-yr}, irrespective of species, age, or sex; (4) the q at Gardner Pinnacles is identical to the q at Necker Island; (5)

commercial CPUE is a reliable index of lobster abundance in the NWHI; and (6) *q* is constant over time.

Area-specific estimates of catchability and recruitment, derived by applying the discrete population model to monthly commercial catch and effort data show no temporal trends (Figs. 11 and 12). Between 1995 and 1999 catchability estimates ranged from 2.1 x 10^{-6} to 2.8 x 10^{-6} ($\bar{x}$ = 2.4 x 10^{-6}) at Necker Island, 1.7 x 10^{-6} to 1.9 x 10^{-6} ($\bar{x}$ = 1.8 x 10^{-6}) at Maro Reef, and 7.8 x 10^{-7} to 8.0 x 10^{-7} ($\bar{x}$ = 7.9 x 10^{-7}) for the entire NWHI. Monthly recruitment estimates for the same time period ranged from 198,000 to 200,000 lobsters ($\bar{x}$ = 199,000 lobsters) at Necker Island, 244,000 to 306,000 lobsters ($\bar{x}$ = 278,000 lobsters) at Maro Reef, and 677,000 to 698,000 lobsters ($\bar{x}$ = 691,000 lobsters) for the entire archipelago.

Alternative estimates of catchability and recruitment, however, are significantly different from the model-derived estimates. While the discrete population models have assumed constant recruitment and the model outputs support this assumption, CPUEs of mature spiny lobster from research surveys at Necker Island show an 80% drop in CPUE between 1988 and 1999. In addition, spiny lobster recruitment to Necker Island also appears to be declining (Fig. 13). Between 1988 and 1999 research survey CPUEs of 2-year-old spiny lobster at Necker Island declined by at least 85% and is inconsistent with the constant recruitment assumption.

Applying a closed-population Leslie depletion estimator (Leslie and Davis, 1939) to the 1997 daily commercial catch (mature unberried spiny and slipper lobsters) and effort data, catchability estimates of 4.7 x 10^{-6} (95% CI = (3.9 x 10^{-6}, 5.7 x 10^{-6})) and 2.0 x 10^{-5} (95% CI = (1.2 x 10^{-5}, 2.8 x 10^{-5})) were derived for Necker Island and Maro Reef, respectively, and are much higher than the 1997 estimates of catchability generated by the discrete population model (2.1 x 10^{-6} for Necker Island; 1.8 x 10^{-6} for Maro Reef). We assume that catchability estimates from Necker Island are specific to spiny lobster as they are the primary target of the commercial fishery there, contributing at least 90% to the reported catch of lobsters from this bank.

An additional estimate of catchability was derived for spiny lobster at Necker Island from the tagging experiments conducted in 1998 and 1999. Baranov's catch equation was used to model the expected number of recaptures, given the known releases, by varying fishing mortality to minimize the difference between the expected and observed number of recaptures. Catchability was then computed using the relationship $F = qf$, where F (fishing mortality) and f (fishing effort) are both known. In 1999, fishing mortality for spiny lobster at Necker Island was estimated at 0.21, higher than the value of 0.14 assumed in the discrete population (regression) assessment model. Similarly, catchability was estimated as 4.6 x 10^{-6}, higher than the value of 2.79 x 10^{-6} estimated by the assessment model. As the tag-recapture estimates are provisional, the goal is to continue tagging spiny lobsters and eventually expand the tagging studies to include slipper lobster. It should be noted, however, that catchability estimated from the tagging experiment is similar to the estimate generated from the Necker Island depletion experiment (4.7 x 10^{-6}).

The different estimates of catchability result in significantly different estimates of exploitable population (Table 4). The inconsistencies in the estimates of catchability and recruitment derived by the different methods exemplify the increasing uncertainty associated with the current methodologies for estimating exploitable population and the need for further model development. Additional problems with current methodologies are explained in the next section.

Shortcomings of the Methodologies for Estimating Exploitable Population.

Continuing research and review have subsequently indicated areas for improvement to better model the lobster stocks. This research has identified the following inadequacies with the present methodologies:

1. <u>Asynchronous dynamics have been observed between bank-specific populations of lobsters in the NWHI, which are not incorporated into the current population model</u>. Lobsters in the NWHI inhabit discrete patches (e.g., banks) that are linked by the dispersal of larvae between patches. The dynamics, under these conditions, cannot adequately be modeled either by treating the system as a single homogeneous population or by treating it as a set of totally independent subpopulations. Therefore, past modeling approaches, which assumed a single homogeneous population may have been inadequate, providing biased assessment results.

2. <u>Estimates of exploitable population are based on a combined (spiny and slipper lobster) commercial CPUE which could promote localized depletion and ultimately result in recruitment overfishing</u>. This tends to be more problematic when one species is locally depleted but continues to be targeted, as is the case with many local populations of lobsters in the NWHI. For example, slipper lobster is the dominant species at Maro Reef and currently the primary target of the commercial fishery there. Because of the low abundance of spiny lobster at Maro Reef it is economically infeasible to fish for them exclusively. However, significant price differentials between the two species (spiny lobster are more valuable than slipper lobster) provide an incentive to fish for spiny lobster as fishermen at Maro Reef (as well as other banks) continue to actively search for them.

3. <u>Poor model fits and biased estimates of exploitable population may result when fisheries switch targets</u>. Commercial fishing at Maro Reef historically targeted spiny lobster but in recent years (1997-99) switched to slipper lobster due to an apparent change in species dominance. Prior to 1990 spiny lobster was the dominant species at Maro Reef; after 1990 slipper lobster was the dominant species. This switch in fishing target has resulted in poor model fits in recent years, limiting our ability to accurately estimate exploitable population.

4. <u>Recruitment is not constant and may be declining</u>. The discrete models used to compute exploitable population have assumed constant recruitment (independent of

population abundance). However, spiny lobster recruitment to Necker Island appears to be declining, despite reductions in fishing effort throughout the NWHI. Assuming that the Necker Island recruitment time series is accurate, the model assumption of constant recruitment is invalid. The observed decline could have serious consequences for NWHI spiny lobster populations. Necker Island is an important source of spiny lobster larvae in the NWHI and will be important for rebuilding spiny lobster populations on adjacent banks.

5. There are conflicting estimates of catchability (q) used to derive exploitable population. Estimates of exploitable population are based on an assumed linear relationship between population size and CPUE, and estimates are derived as $N = \text{CPUE} / q$. Independent estimates of q computed in 1997 from Leslie depletion experiments at Necker Island and Maro Reef are significantly higher than estimates of catchability generated by the discrete population models. These model-based versus experiment-based differences in q result in significantly different estimates of exploitable population and harvest guidelines.

6. Spiny lobster biological data and related assumptions about population dynamics from the 1970s and 1980s form the basis of models used to (1) assess the status and (2) evaluate harvest policies for both spiny and slipper lobster stocks in the NWHI. These models assume no temporal changes in population dynamics parameters and identical dynamics between lobster species. Lobster populations in the NWHI have undergone significant changes in abundance and distribution over the past two decades and many of the biological processes will likely exhibit considerable spatiotemporal variability. In addition, the life histories of spiny and slipper lobsters differ, and it is likely that differences exist between population dynamics parameters (e.g., natural mortality, growth, etc.).

Most of these shortcomings stem from processes that are related to spatial scale and the pooling of species-specific data. Previous assessments did not recognize the importance of space and assumed synchronous dynamics among local populations of lobsters, regardless of species, in the NWHI. Parameter mis-specification can result in biased estimates of various population dynamics parameters including spawning stock biomass, catchability, and recruitment (Fu and Quinn II, 2000).

REFERENCE POINTS

Overfishing in the Crustaceans FMP is currently defined in terms of recruitment overfishing, and the current indicator used to assess overfishing is a species-combined spawning potential ratio (SPR). The SPR is the ratio of the spawning potential per recruit of a cohort in a fished condition relative to that in an unfished condition (Goodyear, 1980; 1993). SPR is inversely proportional to fishing effort, varying from 1 (when there is no fishing) to 0 (with infinite fishing). There are two established SPR thresholds in the Crustaceans FMP: a 0.20

minimum SPR threshold level below which the stock is considered overfished and a warning range from 0.20 to 0.50 indicating the need for additional conservation measures.

The spawning potential ratio of NWHI lobsters is computed using an equilibrium spawning biomass-per-recruit equation (Beverton and Holt, 1957). Hence, whether or not a stock is above or below the SPR thresholds is determined assuming equilibrium conditions; i.e., the equilibrium SPR resulting from constant fishing mortality rates and biological parameters. The numerator of the current SPR level is the spawning potential that would be realized if the fishery continued to operate at a constant fishing mortality equal to that in the current year; the denominator is the spawning potential that would be realized if there were no fishing.

As previously stated the SPR does not consider the level of recruitment or trends in spawning biomass and thus does not adequately describe the status of stocks (Haight and DiNardo, 1995; DiNardo et al., 1998). The inadequacy of using a per-recruit approach to determine biological reference points for management has recently been expounded upon by the late Ray Beverton (1998). Because of inherent estimation problems with SPR calculations nationwide, future regulatory guidelines for fishery management in the United States under the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) may require maximum sustainable yield (MSY)- and optimum yield (OY)-based approaches to assess overfishing (Restrepo et al., 1998). Performance indicators and threshold levels for the NWHI commercial lobster fishery under MSY- and OY-based approaches were developed by the NMFS-HL and are outlined in DiNardo and Wetherall's administrative report (in prep).

CURRENT STATUS OF STOCKS

Based on SPR and relative abundance data the current status of the NWHI lobster stocks can be summarized as follows:

- The estimated 1996-2000 SPR values for lobsters from Necker Island and Maro Reef are presented in Tables 5 and 6 and, depending on the value of q used, wide variation between the estimates is apparent. Estimates of q are available from both the tagging and depletion experiments (scenario 1) as well as the discrete population model (scenario 2) applied to monthly catch and effort data from 1983 through 1999. For each scenario, estimates of SPR were computed assuming a retain-all fishery and assuming that the q associated with each scenario persisted from the present back to 1996. Because the present estimates of q differ from those reported in earlier status of stock reports, the SPR estimates contained in this report differ from those previously reported.

  The different bank-specific estimates of q and subsequent impact on SPR estimation exemplifies the increasing parameter uncertainty associated with key assessment parameters. Under scenario 1, lobsters at Maro Reef were overfished from 1997 to 1999 (Table 5), while at Necker Island overfishing occurred in 1996 and 1997 (Table 6). In 1998 and 1999, SPRs at Necker Island were above the minimum threshold (0.2) but within the warning range, indicating the need for additional conservation measures. Under scenario 2, SPRs were all above the minimum threshold (0.2) regardless of bank. From 1997 to 1999 SPRs at Maro Reef were also above the warning level (0.5) while SPRs at Necker Island were within the warning range in 1996 and 1997, before increasing above the warning level. The commercial fishery was closed in 2000 and SPR, regardless of scenario, is estimated to be 1.0.

Based on estimates of q from the discrete population model (scenario 2) and independent sources (scenario 1), SPR time series of unberried mature lobsters from Necker Island and Maro Reef are depicted in Figures 14 and 15, respectively. While we present SPR values from 1983 to the present it should be noted that the NWHI lobster fishery has been managed to prevent recruitment overfishing by maintaining the SPR above the 0.20 minimum threshold level only since 1990. Under scenario 1, SPR at Necker Island declined from 0.73 in 1983 to 0.20 in 1990 and has since increased (Fig. 14). In 1999 it was 0.72 and in 2000 it was 1.0. SPR at Maro Reef declined from 0.94 in 1983 to 0.28 in 1988 and has also increased since then. In 1999 it was 0.76 and in 2000, 1.0. Under scenario 2, SPRs at Necker Island and Maro Reef were generally slightly above or below the overfishing threshold through the early 1990s (Fig. 15). After 1994, SPRs at both banks increased but were generally within the warning range.

- Since 1983, NWHI lobster CPUEs from the commercial fishery have generally declined. Concurrent with the decline was a shift in the spatial distribution of catch and fishing effort which likely disguises actual trends in abundance. According to Caddy (1989) all important processes in invertebrate fisheries have a spatial component, including growth and mortality rates, which may vary spatially owing to differences in habitat quality. Because of this it may be inappropriate to set harvest rate uniformly over large areas.

- Local populations of lobster in the fourth management area showed a 50% drop in commercial CPUE between 1983 (2.21) and 1987 (1.12), and there was generally no commercial fishing in this area for approximately 10 years prior to 1998. In this management area the average commercial CPUE was approximately 0.6 in 1999, and on many of the banks the CPUE was less than 0.3. The observed lack of any appreciable population rebuilding at these banks is indicative of poor recruitment.

- Despite the apparent low abundance of spiny lobster at many banks in the NWHI the commercial fishery continued to target spiny lobster and any spiny lobster-directed commercial fishing effort may be excessive.

- CPUEs of mature spiny lobster from research surveys at Necker Island continue to decline; between 1988 and 1999 an 80% drop in CPUE for mature spiny lobster was observed. Spiny lobster recruitment at Necker Island also appears to be declining. Necker Island is an important source of spiny lobster larvae in the NWHI and will be important for rebuilding spiny lobster populations on adjacent banks.

- Excessive fishing likely led to the depletion of many local populations of spiny lobster in the NWHI. Despite significant reductions in commercial fishing activities in the NWHI, local populations of spiny lobster remain depressed, exhibiting no signs of rebuilding.

As previously stated, there is increasing uncertainty with current parameterization of the NWHI lobster population models used to assess stock status, and model-derived estimates (e.g., exploitable population) should be viewed with caution. Much of the uncertainty stems from processes that are related to spatial scale and the treatment of data (pooled across species). Previous assessments did not recognize the importance of spatial heterogeneity and assumed synchronous dynamics among local populations of lobsters, regardless of species, in the NWHI. Parameter mis-specification can result in biased estimates of various population dynamics parameters including spawning stock biomass, catchability, and recruitment. Improving lobster stock assessments will require better population models with sufficient spatial and species resolution that explicitly characterize the dependence between local lobster populations. The development of spatially structured population, or what are commonly referred to as metapopulation models for NWHI lobster populations represents a new paradigm and should provide for more reliable estimates of stock size.

NEW PARADIGMS - A METAPOPULATION APPROACH

Historical Perspective

Several approaches have been used since 1983 to model NWHI lobster populations. From 1985 to 1987, lobster yield was estimated using surplus production methods. After 1988, a discrete population model was fit to the NWHI commercial data (pooled across all banks) to estimate population size and biological parameters (Haight and Polovina, 1993). The model expresses the number of exploitable lobsters (all species combined) in a given month as a function of the number of exploitable lobsters in the previous month, adjusted for natural mortality, fishing mortality, and recruitment. Pooling the commercial data across banks disregarded spatial heterogeneity and assumed synchronous dynamics among local populations of lobsters in the NWHI. In 1992, catch quotas were adopted as a management tool in the NWHI lobster fishery and the discrete population model of Haight and Polovina (1993) was used to estimate the exploitable population of lobsters in the NWHI.

Spatial management commenced in 1998 requiring estimates of exploitable population for each of the four management areas, and the discrete population model was used to compute exploitable population estimates. Continuing differences in recruitment patterns and species composition between the northwestern and southeastern segments of the NWHI demonstrated the need for spatial management and region-specific estimates of exploitable population size. The development of spatially structured estimates of exploitable population and subsequent harvest guidelines are also consistent with the recommendations of a Fishery Review Panel convened in March 1997 to evaluate stock assessment and management of lobsters in the NWHI, the Council, and various Council advisory committees. It is of interest to note that spatial management of the NWHI lobster fishery was initially recommended during the early phases of the fishery to prevent local depletion, but was rejected by the Council (Tim Smith, pers. commun.).

While the discrete population model used to estimate exploitable population size may have been an adequate starting point for spatial management purposes, continuing research and review have subsequently indicated areas for improvement to better model the lobster stocks. In particular, recent advances in our understanding of the (1) spatial structure of NWHI lobster populations and (2) dynamics of larval transport indicate that lobster populations in the NWHI constitute a metapopulation--a group of populations inhabiting discrete patches of suitable habitat that are connected by the dispersal of individuals between habitat patches (Hanski, 1991). The population structure and spawning strategy of NWHI lobsters support the definition of a metapopulation reasonably well. Genetic studies indicate that a single homogeneous population of spiny lobster occurs in the NWHI (Shaklee and Samollow, 1984; Seeb et al., 1990), adding additional support to the metapopulation notion. No genetic studies have been conducted on slipper lobster.

The Metapopulation Approach

The simplest metapopulation model considers a large number of habitable patches where the proportion of patches occupied (p) at any time (t) depends on the proportion of patches occupied at time ($t-1$) and the rates of population extinction and colonization (Levins, 1969). The rate of change in p is given by

$$dp/dt = mp(1 - p) - ep \tag{5}$$

where m and e are the colonization and extinction probabilities, respectively. At equilibrium, $dp/dt = 0$ and the proportion of patches occupied is $p^* = 1 - e/m$, which requires that $e/m < 1$ for metapopulation persistence. To account for habitat loss, consider that a fraction $1 - h$ of the patches is destroyed. The proportion of patches suitable for colonization that remain unoccupied changes from $1 - p$ to $h - p$, and the rate of change in p is then (May, 1991)

$$dp/dt = mp(h - p) - ep \tag{6}$$

and the equilibrium solution becomes $p' = h - e/m$, requiring now that $e/m < h$ for metapopulation persistence. The Levins model ignores spatial structure and within patch population dynamics and assumes that all populations are identical regarding extinction and colonization probabilities. Recent enhancements to the Levins model account for stochastic processes within each local population (patch) (Verboom, Lankester, and Metz 1991) and spatial structure (Hanski, 1994). Despite the simplicity of the Levins model it remains attractive because of its generality and qualitative agreement with the results of more realistic models.

Prior to any anthropogenic activities (e.g., habitat degradation and localized depletion by commercial fisheries) in the NWHI the extinction rates (e) were probably low and migration rates (m) between populations high such that $e/m \approx 0$, meaning that $p^* \approx 1$. While population sizes may have fluctuated by orders of magnitude through time, only rare environmental catastrophes resulted in years with total recruitment failure. The equilibrium solution of eq. (6) and the associated inequality required for metapopulation persistence, that $e/m <$ h, may relate directly to the causes of spiny lobster declines in the NWHI. The above inequality is often not satisfied in disturbed ecosystems, which reduces the carrying capacity of the habitat and the mean growth rate of the population, increasing the chance of population extinction due to demographic and environmental stochasticity (Harrison, 1991). As local populations of spiny lobster were fished down (and locally depleted) the population became more fragmented; e increased and m decreased, resulting in an increase in e/m. The fishing down of spiny lobster also created a surplus of available habitat (areas previously occupied by spiny lobster), which based on commercial fishing and research survey data, is now occupied by slipper lobster. The observed species replacement is a form of anthropogenic-induced habitat degradation (for spiny lobster), resulting in further increases in e/m. As the number of local populations fished down increases, e/m approaches h; how fast e/m approaches h depends on the relative importance of the spiny lobster populations fished down (in terms of being a recruitment source), the spatial correlation between local populations, and the growth rate of the slipper lobster population. While there are no estimates of e or m for lobster in the NWHI, all banks have experienced significant declines in spiny lobster by fishing, and on most banks both the population size and spatial distribution of slipper lobster appear to be increasing.

Dependence between local populations of spiny lobster in the NWHI implies that it is conceivable for a bank to undergo population declines even though the bank experiences little or no anthropogenic activities. While previously attributed solely to environmental factors, the decline of spiny lobster at Laysan Island may provide an example of indirect impacts resulting from localized depletion on adjacent banks. Despite experiencing limited commercial fishing (none of which was directed at spiny lobster), spiny lobster age-specific CPUEs from research surveys conducted at Laysan Island from 1977 to 1991 generally declined (Haight and Polovina, 1992). Research trapping at Laysan Island in 1996, though limited in spatial distribution, documented further declines in spiny lobster age-specific CPUEs (Robert Moffitt, pers. comm.) (Fig. 16). While it is difficult to quantify the magnitude of the decline because of non-standardized survey methodologies between years, a decline is apparent; in 1977 the average spiny lobster CPUE was approximately 1.5 and in 1996 spiny lobster were virtually absent from Laysan Island.

Concurrent with the observed declines in CPUE at Laysan Island was the systematic fishing down and local depletion of spiny lobster populations at adjacent banks that are potential sources of recruitment for Laysan Island. Thus, the recruitment failure observed at Laysan Island may have initially resulted from a decline in spiny lobster spawning biomass in the NWHI caused by commercial fishing on adjacent banks and, as the biomass was reduced further, depressed still further by environmental factors (Harrison, 1991). This is only a hypothesis as it is difficult (if not impossible) to determine causality for the observed decline at Laysan Island given the confounding of effects and the paucity of data. It is of interest to note, however, that in 1986 fisherman suggested that there was a dependence between local populations of spiny lobster in the NWHI and that heavy fishing in one area (Necker Island) could cause a decline in another (Laysan Island)[1].

Management Implications and Data Requirements for Stock Assessments

Treating spiny and slipper lobsters in the NWHI as metapopulations is consistent with the available data and represents a departure from the status quo. Given the dependence among local populations of spiny lobster in the NWHI, overfishing or depletion of local populations could result in catastrophic impacts to the population as a whole (e.g., reduction in average recruitment or recruitment failure), particularly when a large number of local populations or the most productive populations are overfished. Also, when spatial correlation among local populations is high, bank-specific relationships between population size and fishing can become decoupled, masking the true impact of fishing. The decline of spiny lobsters at Laysan Island may provide an example of this decoupling. A major component of an effective management plan for spatially structured populations, such as spiny lobster (or even slipper lobster), is the establishment of refugia. Setting aside refuges provides a buffer against the risk of overfishing the system (Guenette et al., 1998).

This paradigm shift also changes the data requirements for NWHI lobster stock assessments. While the discrete population model relied solely on commercial catch and effort data as input, metapopulation models require data (both biological and fishery related) with greater spatial resolution. Because of life history differences between spiny and slipper lobsters, the models may also need to be species-specific. The increased data requirements will require modifications to the existing research plan to facilitate model development, and elements of the research plan are outlined below.

NWHI LOBSTER RESEARCH AND MONITORING PLAN

The NMFS-HL has developed a research and monitoring plan which addresses the shortcomings noted above and will allow for more accurate estimates of population size. It should be noted that the plan was developed prior to the establishment of the NWHI Coral Reef Ecosystem Reserve and may require slight modifications. The plan includes research in the areas of population modeling, population dynamics, and monitoring and specifics of the plan are outlined below. Platforms for the field component of the plan include the annual NMFS NWHI lobster research survey and research charters. While the proposed research plan outlines the types of research needed to advance our understanding of the NWHI lobster populations, how

[1]Agard, L. 1986. Lobster battle heating up. Hawaii Fishing News 11:18-19.

much of the research gets implemented is unclear given uncertainties about the NWHI lobster fishery.

Stock Assessment Models

- Develop species-specific models to estimate exploitable population size that incorporate fishery-dependent, fishery-independent, and environmental data at appropriate spatial scales. The purpose of this research is to improve the discrete population model presently used to estimate exploitable population size at Necker Island (Haight and Polovina, 1993) and develop better alternative models that make use of additional data, thereby relaxing assumptions of the current model. The models will be age- or size-based and sex-specific, incorporating information from the research areas discussed below.

- Develop robust estimators for stock status determination criteria (e.g., spawning stock biomass) that are consistent with the spatial management regime. These reference points are required under the guidelines for the MSFCMA.

Life History/Population Dynamics

- Develop and implement methods to estimate lobster life history/population dynamics parameters (e.g., growth, size-at-maturity, natural mortality, etc.) using length-based methods or tagging experiments. Rigorously analyze existing spiny lobster tagging data from Necker Island and, if possible, expand spiny lobster tagging experiments to other banks. Conduct tag evaluation studies to determine an appropriate tag for slipper lobsters and, given sufficient resources, implement a slipper lobster tagging experiment at Maro Reef.

- Develop robust methods of indexing juvenile abundance. A provisional abundance index was developed for spiny lobster at Necker Island based on data from the research assessment cruises; these data will be rigorously analyzed. To the extent possible, slipper lobster indices will be developed and procedures to quantify larval dispersal rates between banks will be explored.

Catch and Catch Per Unit Of Effort

- Develop comprehensive approaches to the analysis of CPUE variability on appropriate time scales and calculate a standardized time series of CPUE. The time series will be updated as data become available.

- Evaluate recommendations to reduce discard mortality.

Fishery Monitoring

- Develop and implement additional collaborative research programs involving industry in the NWHI.
- Expand monitoring and data reporting requirements as needed.

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Table 1. Information matrix describing the temporal extent of NWHI lobster monitoring programs and quality of data collected.

Data and Source		Year																	
		1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Fishery-Dependent	Catch & Effort	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
	Discards	◗	◗	◗	◗	◗	◗	◗	◗	◗	◗	◗	◗	●	●	●	●	●	
	Fishing Loc.	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
	Fishery Size Comp.			○										●		●	●	●	
	Gear Type																		
	Fishery Perform.															◗	◗	◗	
Fishery-Independent	Catch & Effort		●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●
	Bycatch		●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●
	Fishing Loc.		●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●
	Pop. Size Struct.		○	○	○	○	○	○		○	○	○	○	○	○	○	○	○	○
	Size At Maturity																○	○	○
	Habitat Map.																○	○	○
	Gear Type		●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●

Table 2. Information matrix describing the spatial resolution of NWHI lobster monitoring programs and quality of data collected.

Data and Source		Bank													
		Nihoa	Necker I.	FFS	Brooks	St. Rog.	Gardner	Raita	Maro	Laysan	Pioneer	Lisian.	P & H	Midway	Kure
Fishery-Dependent	Catch & Effort	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Discards	◗	◗	◗	◗	◗	◗	◗	◗	◗	◗	◗	◗	◗	◗
	Fishing Location	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Fishery Size Composition	○	○	○	○	○	○	○	○		○	○	○		○
	Gear Type														
	Fishery Performance		◗						◗						
Fishery-Independent	Catch & Effort		●	○		○			●	○					
	Bycatch		●						●						
	Fishing Location		●	○		○			●	○					
	Population Size Structure		○						○	○					
	Size at Maturity		◗						◗						
	Habitat Mapping		◗						◗						
	Gear Type		●	●		●			●	●					

Table 3.--Summary of catch and effort data from federal logbooks for the NWHI lobster fishery, 1983-2000.

Year	No. vessels	No. trips	No. banks	Trap hauls	Spiny lobster				Slipper lobster				Reported landings	Reported discards	Total reported catch
					Mature	Immature	Berried	Total	Mature	Immature	Berried	Total			
1983	4	19	3	64,000	158,000	51,000	10,000	218,000	18,000	6,200	1,700	26,000	176,000	68,000	244,000
1984	13	41	7	371,000	677,000	239,000	75,000	991,000	271,000	9,000	8,000	288,000	948,000	331,000	1,279,000
1985	17	66	13	1,040,000	1,002,000	355,000	132,000	1,489,000	1,029,000	96,000	121,000	1,246,000	2,031,000	705,000	2,736,000
1986	16	62	16	1,290,000	843,000	298,000	153,000	1,294,000	1,005,000	55,000	121,000	1,181,000	1,848,000	627,000	2,475,000
1987	11	40	12	805,000	393,000	233,000	101,000	727,000	395,000	36,000	43,000	474,000	788,000	414,000	1,202,000
1988	9	29	13	834,000	888,000	279,000	115,000	1,282,000	168,000	69,000	41,000	278,000	1,056,000	504,000	1,560,000
1989	11	33	13	1,070,000	944,000	369,000	169,000	1,482,000	216,000	69,000	49,000	334,000	1,160,000	655,000	1,815,000
1990	14	45	14	1,180,000	591,000	464,000	181,000	1,236,000	184,000	56,000	67,000	307,000	775,000	769,000	1,544,000
1991	9	21	5	297,000	132,000	192,000	29,000	353,000	35,000	8,700	6,000	49,700	167,000	236,000	403,000
1992	12	28	9	685,000	248,000	278,000	82,000	608,000	163,000	48,000	29,000	240,000	411,000	437,000	848,000
1993*	---	---	---	----	----	----	----	----	----	----	----	----	----	----	----
1994	5	5	5	168,000	85,000	61,000	39,000	185,000	46,000	28,000	11,000	84,000	131,000	139,000	270,000
1995**	1	1	3	64,000	35,000	34,000	21,000	90,000	3,300	7,400	***	11,500	38,300	61,000	99,300
1996	5	5	2	115,000	123,000	----	42,000	165,000	18,000	----	4,000	22,000	187,000	2,000	189,000
1997	9	9	4	178,000	140,000	----	36,000	176,000	121,000	----	13,000	134,000	310,000	***	310,000
1998	5	9	12	171,000	69,000	----	13,000	82,000	113,000	----	16,000	129,000	211,000	***	211,000
1999	6	6	13	236,000	73,000	----	13,000	86,000	134,000	----	12,000	146,000	232,000	***	232,000
2000*	---	---	---	----	----	----	----	----	----	----	----	----	----	----	----

* Fishery closed
** Experimental fishery
*** Less than 1000 lobsters

Table 4. Estimates of lobster exploitable population (species combined) on July 1, 2000 based on the different estimates of catchability.

Source of Catchability Estimate			
Bank	Model derived[1]	Depletion estimate[2]	Tagging experiment[3]
Necker Island	446,627	265,470	271,241
Maro Reef	654,954	62,943	

[1] $q_{NI} = 2.8 \times 10^{-6}$ $q_{MR} = 1.9 \times 10^{-6}$
[2] $q_{NI} = 4.7 \times 10^{-6}$ $q_{MR} = 2.0 \times 10^{-5}$
[3] $q_{NI} = 4.6 \times 10^{-6}$

Table 5. Maro Reef SPRs from 1997 to 2000 under an optional retain-all retention policy.

SPR		
Year	Scenario 1*	Scenario 2**
1997	0.16	0.77
1998	0.2	0.79
1999	0.08	0.67
2000	1.0	1.0

*q for spiny lobster = 4.6×10^{-6} and for slipper lobster = 2.0×10^{-5}
**q for both species = 1.92×10^{-6}

Table 6. Necker Island SPRs from 1996 to 2000 under an optional retain-all retention policy.

	SPR	
Year	Scenario 1*	Scenario 2**
1996	0.16	0.33
1997	0.15	0.3
1998	0.33	0.5
1999	0.46	0.61
2000	1.0	1.0

*q for spiny lobster = 4.6×10^{-6} and for slipper lobster = 2.0×10^{-5}
**q for both species = 2.79×10^{-6}

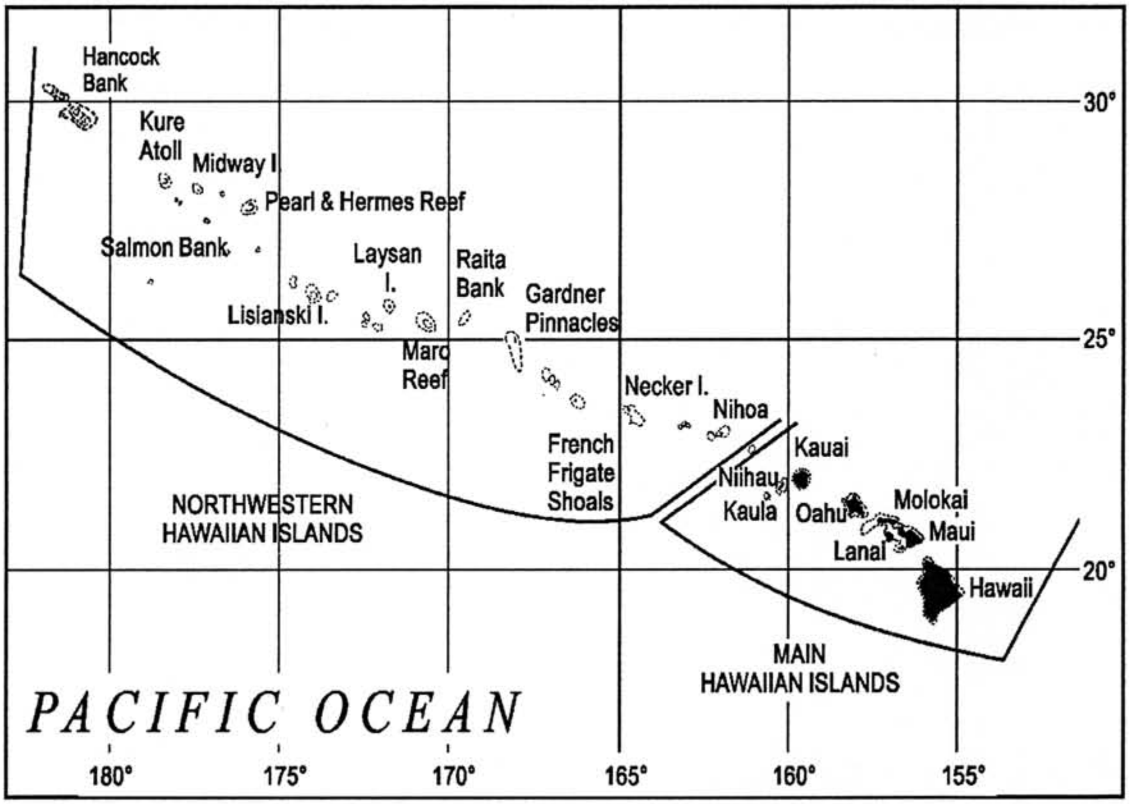

Figure 1. The Hawaiian Archipelago.

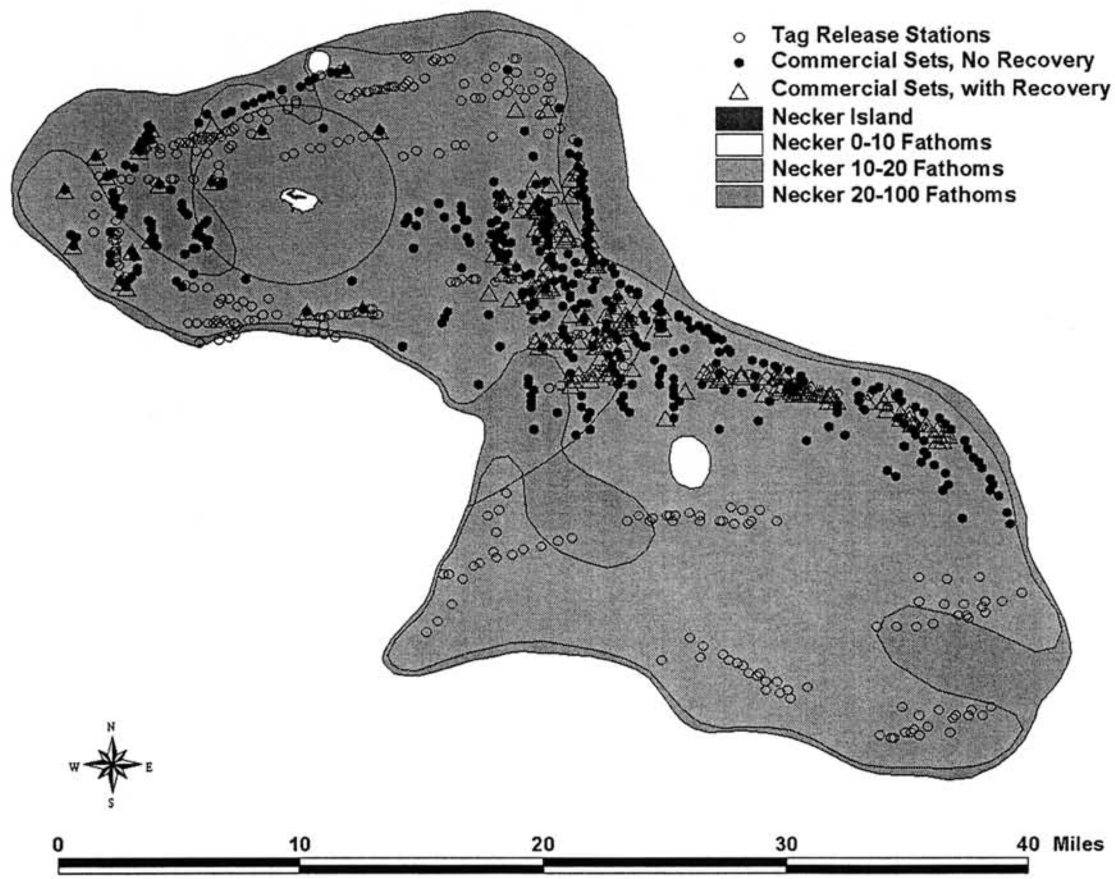

Figure 2. Location of tag release sites, commercial fishing and tag recovery sites during the 1998-99 Necker Island spiny lobster tagging experiment.

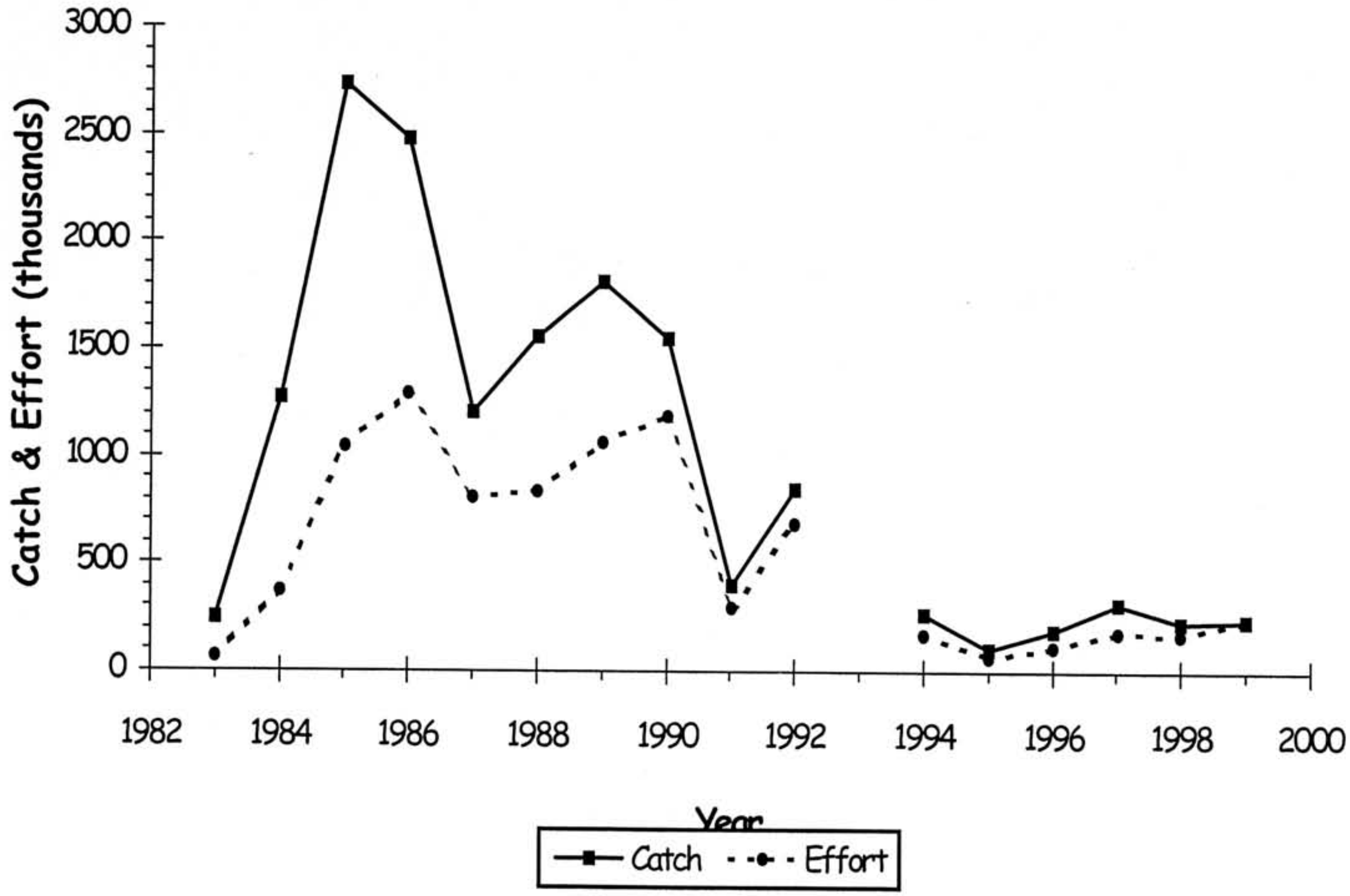

Figure 3. Annual metrics of reported catch and fishing effort (trap hauls) in the NWHI commercial lobster fishery.

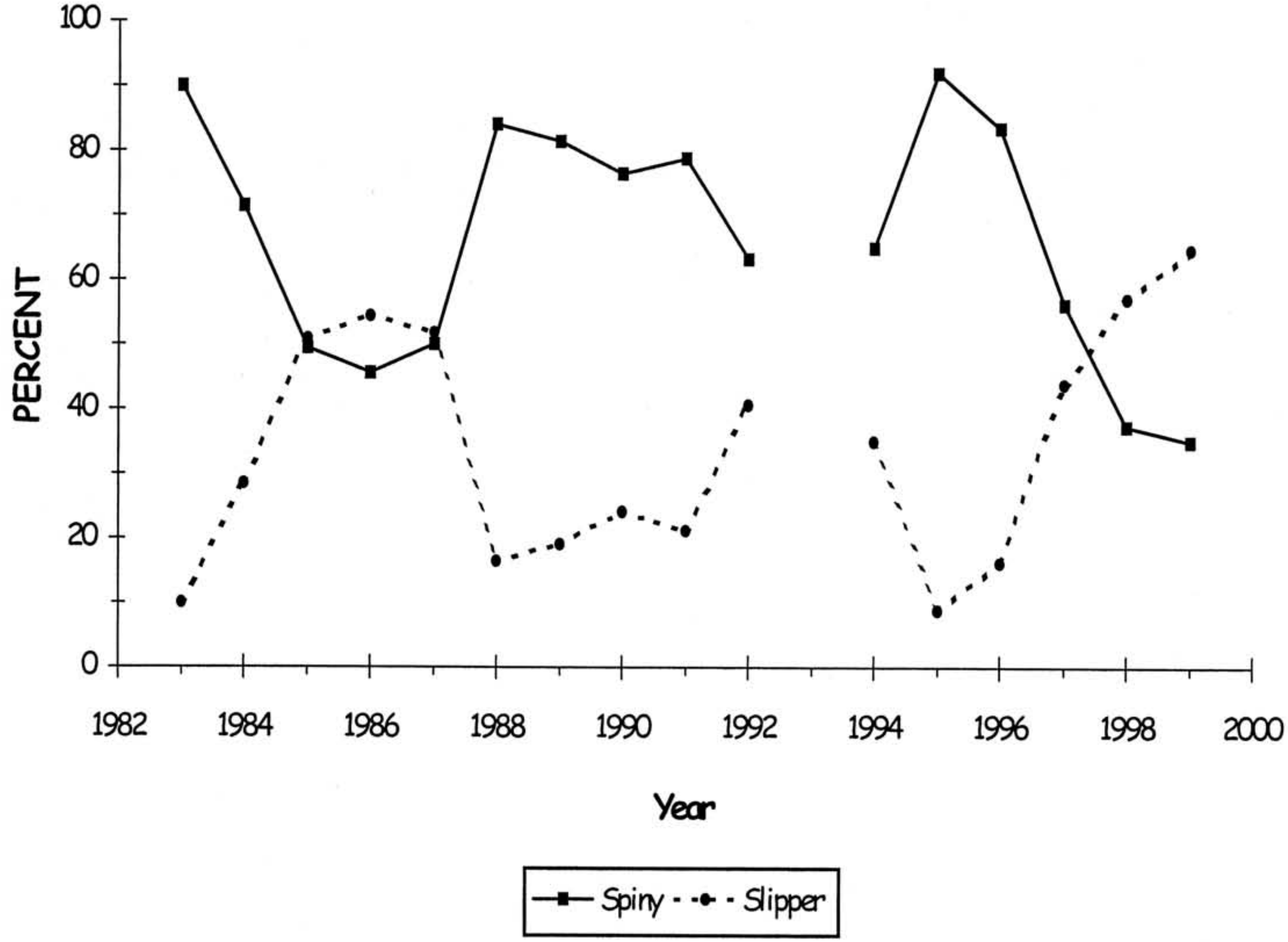

Figure 4. Annual percentages on mature spiny and slipper lobster catches (see text for legal definition).

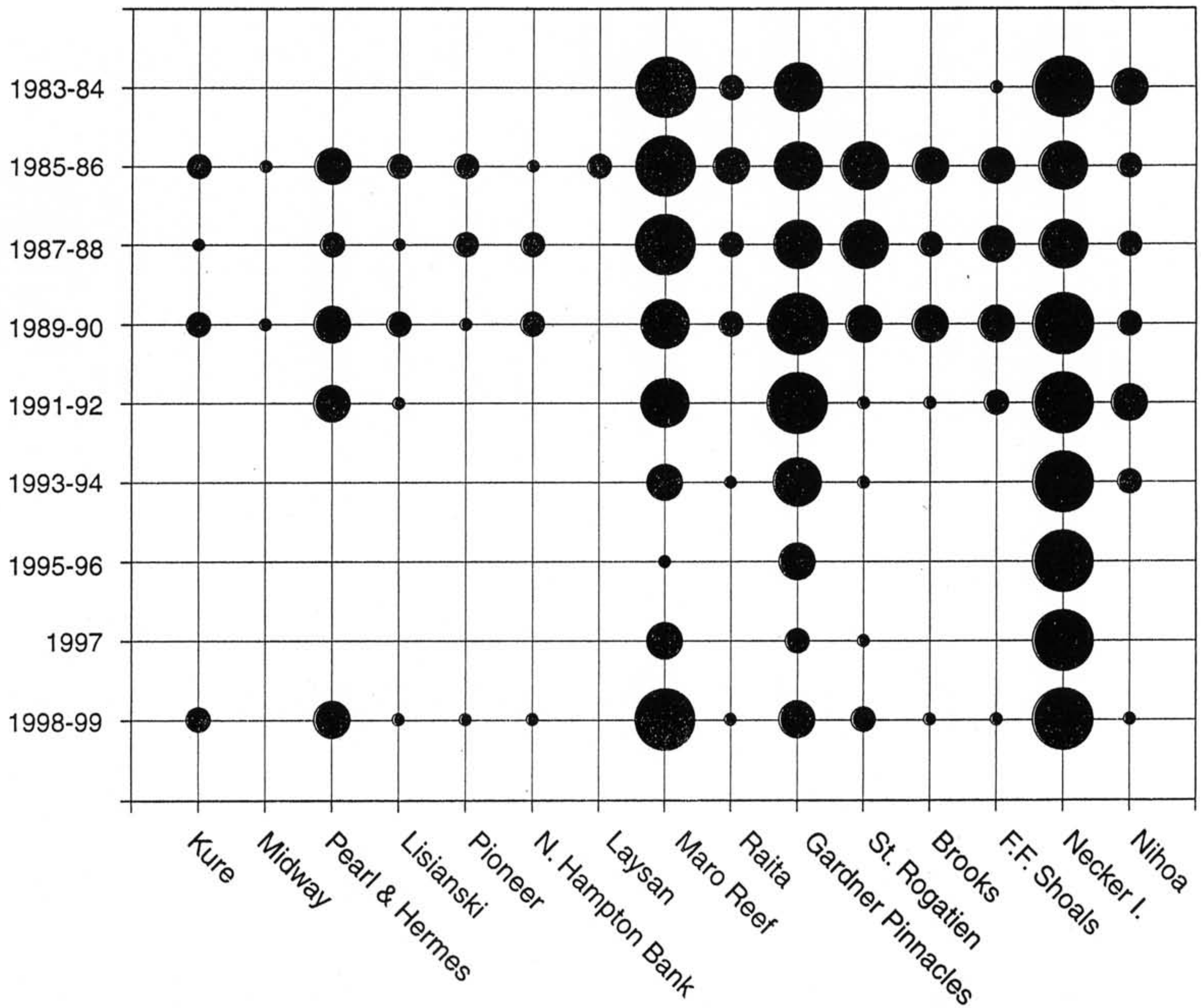

Figure 5. Spatial distribution of commercial fishing effort in the NWHI lobster trap fishery. Within each time step a circles diameter represents the relative magnitude of reported fishing effort; the larger the circle the greater the reported fishing effort.

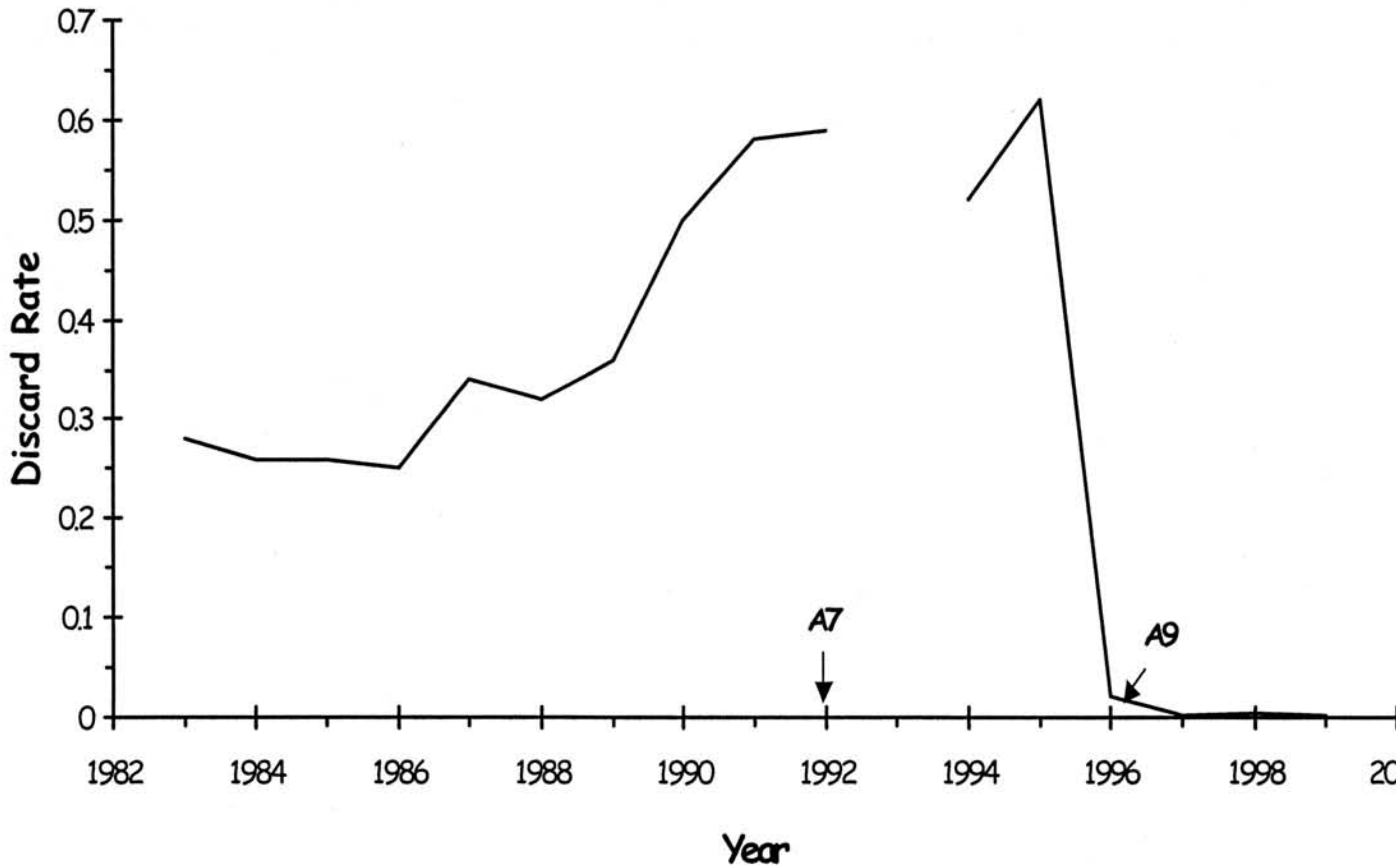

Figure 6. Annual estimates of the reported discard rate for lobsters from the NWHI lobster trap fishery. A7 and A9 show when Amendments 7 and 9 were implemented, respectively.

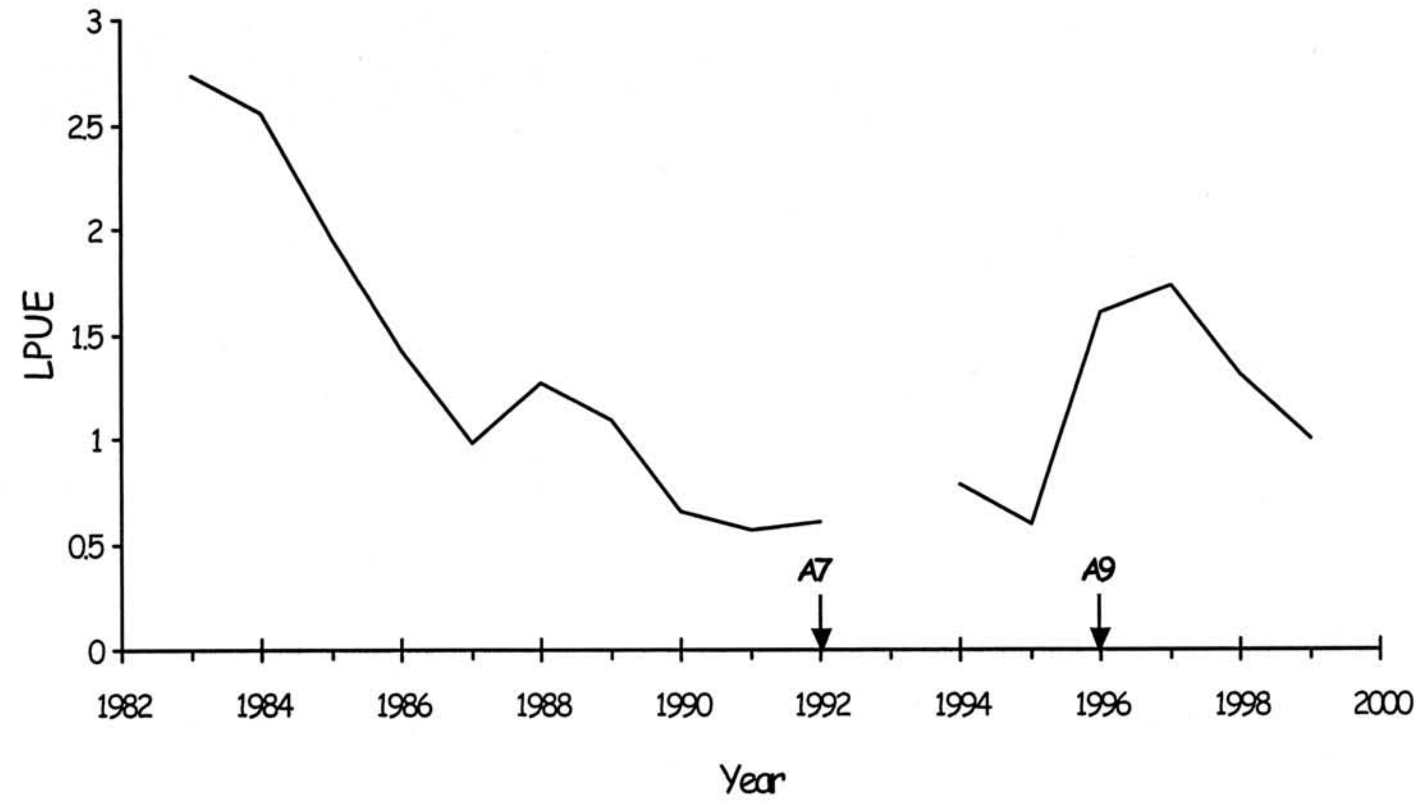

Figure 7. Annual commercial LPUE for the NWHI lobster trap fishery, 1983-99. A7 and A9 show when Amendments 7 and 9 were implemented, respectively.

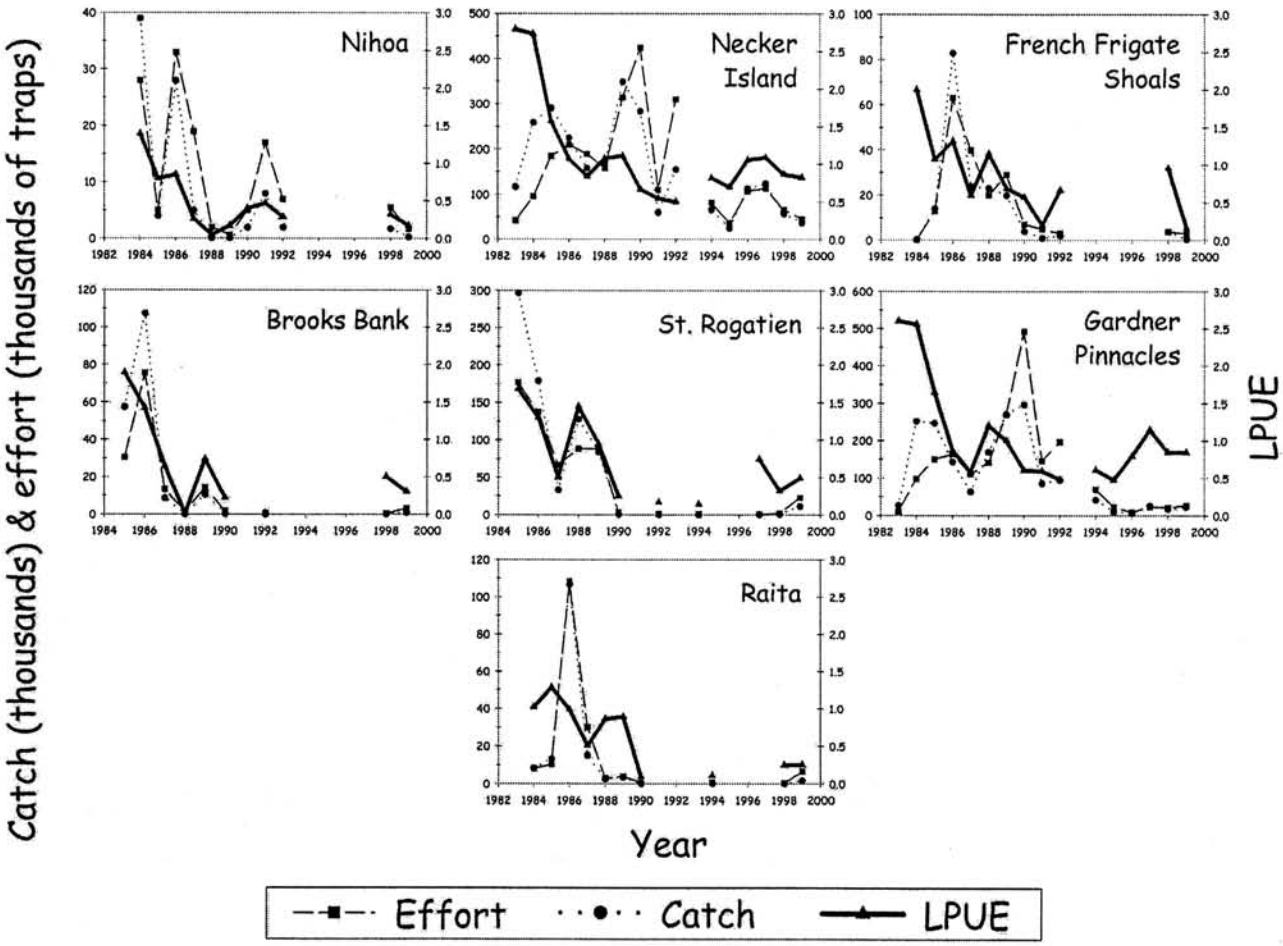

Figure 8a. Bank-specific annual metrics of LPUE, fishing effort (trap hauls) and catch from the NWHI lobster fishery.

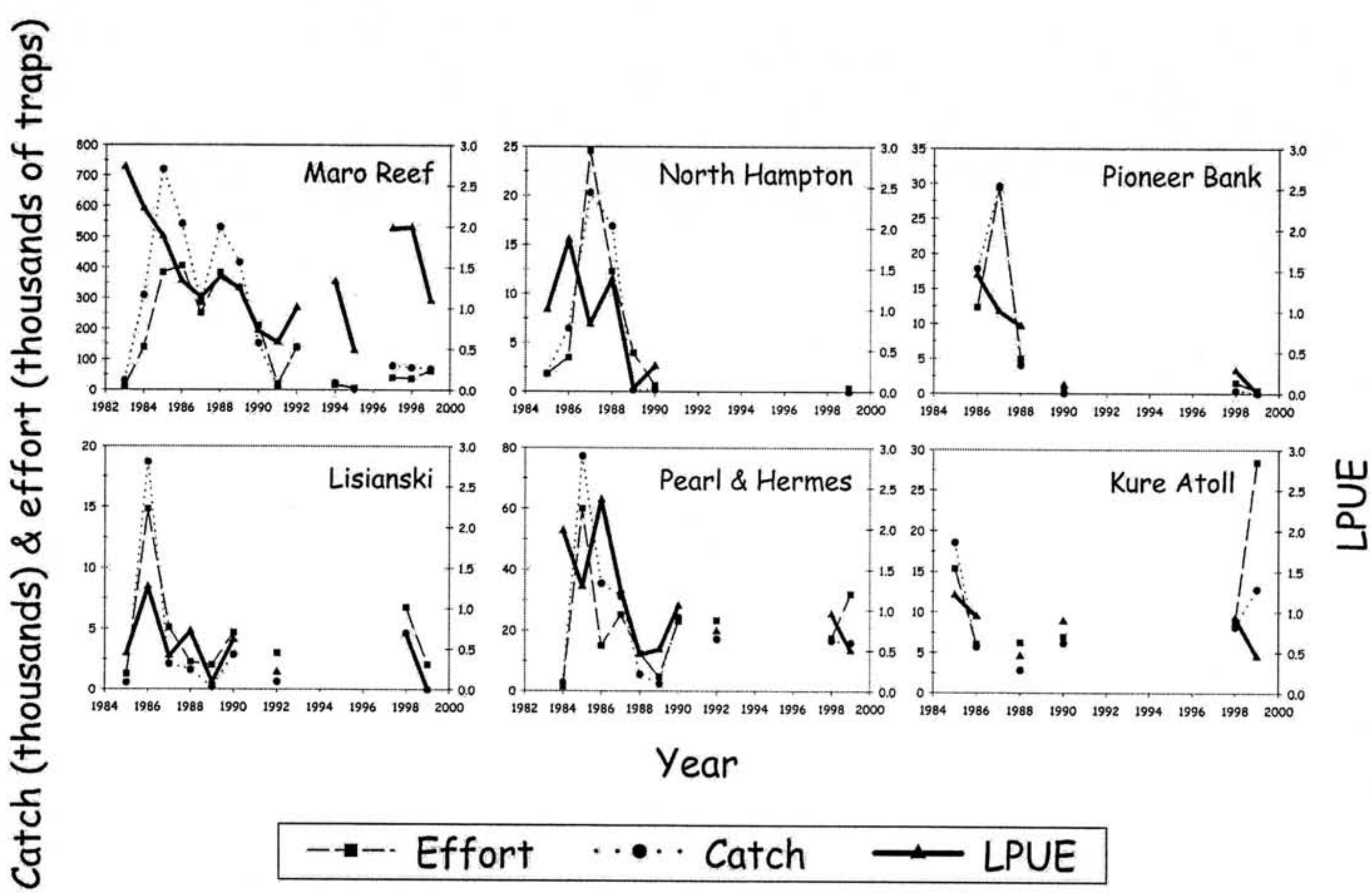

Figure 8b. Bank-specific annual metrics of LPUE, fishing effort (trap hauls) and catch from the NWHI lobster fishery.

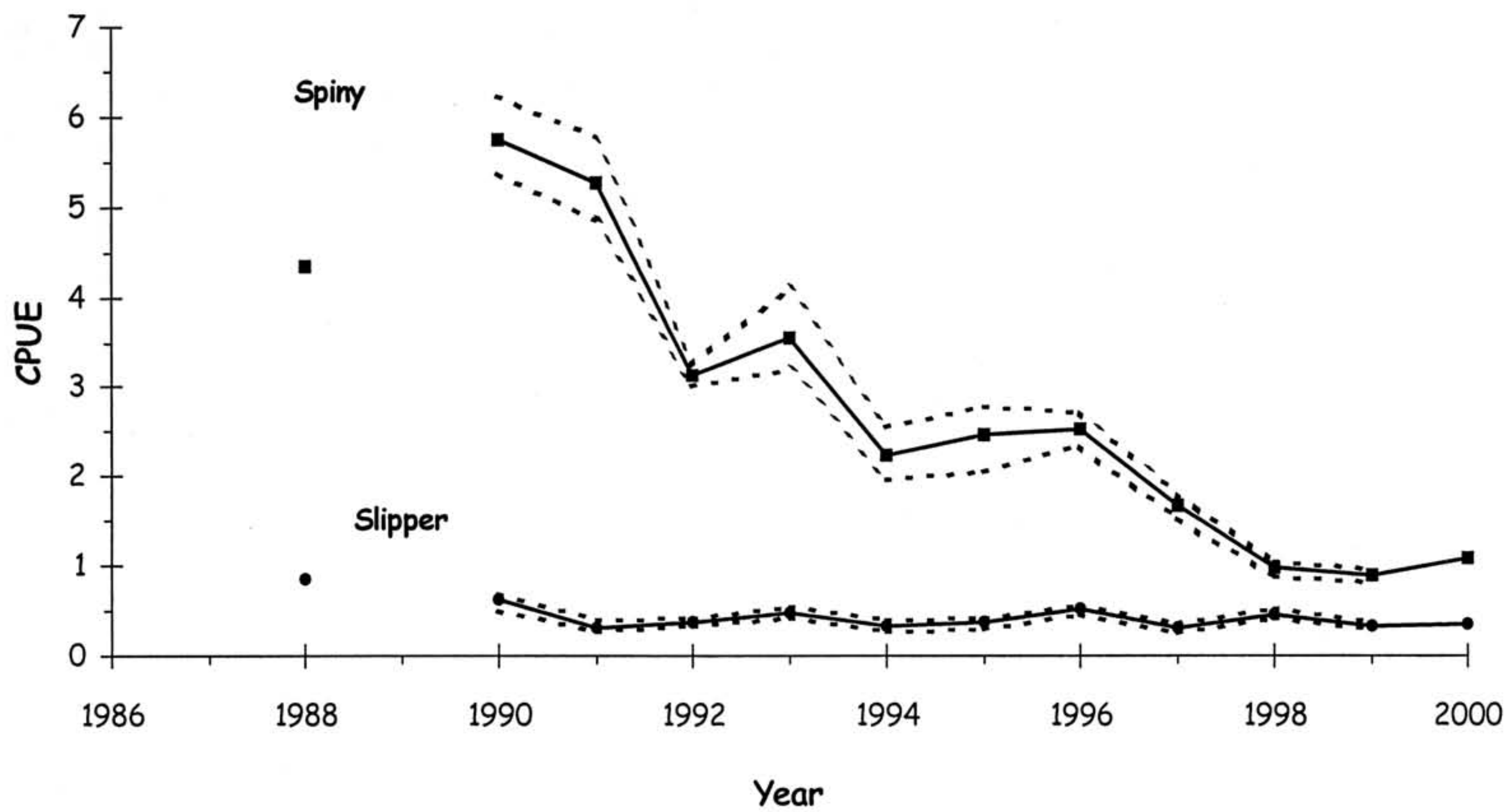

Figure 9. Annual metrics of spiny and slipper lobster CPUEs from the *Townsend Cromwell* research surveys at Necker Island.

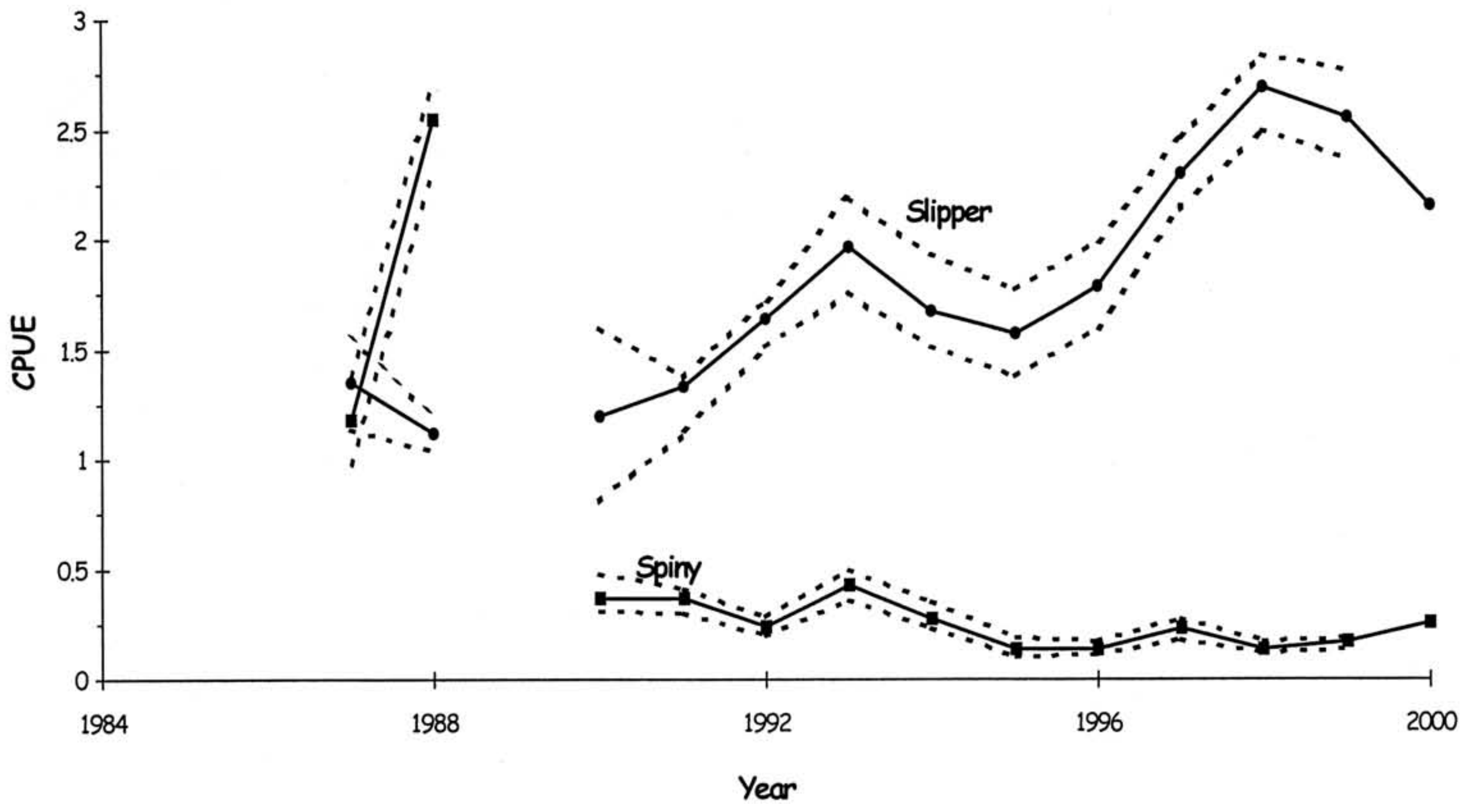

Figure 10. Annual metrics of spiny and slipper lobster CPUEs from the *Townsend Cromwell* research surveys at Maro Reef.

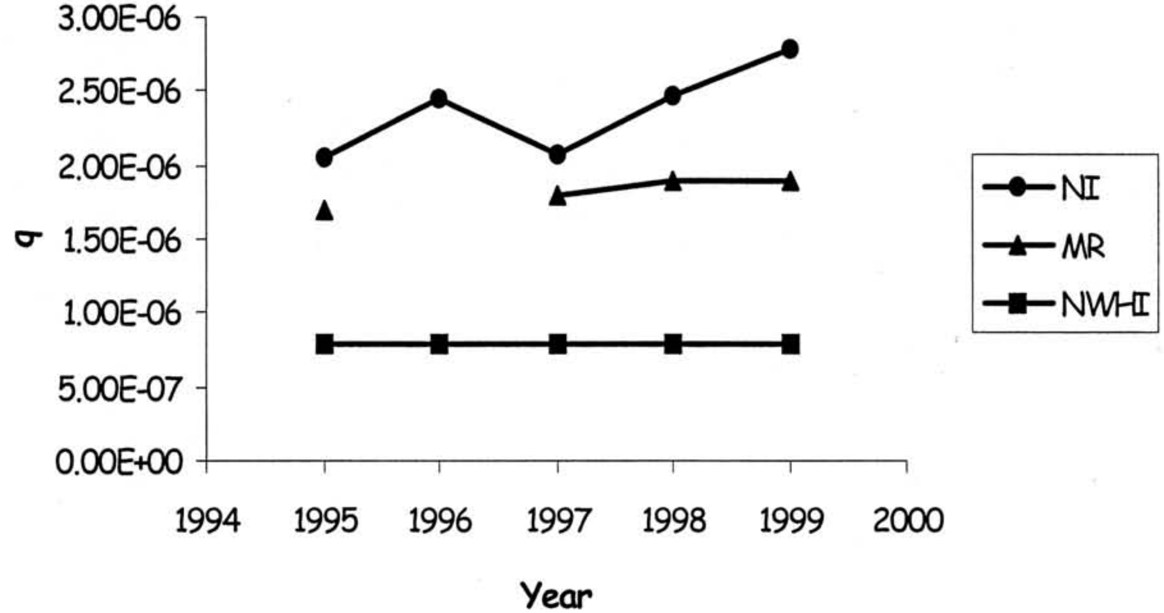

Figure 11. Model derived estimates of catchability for Necker Island, Maro Reef, and the NWHI from 1995-99.

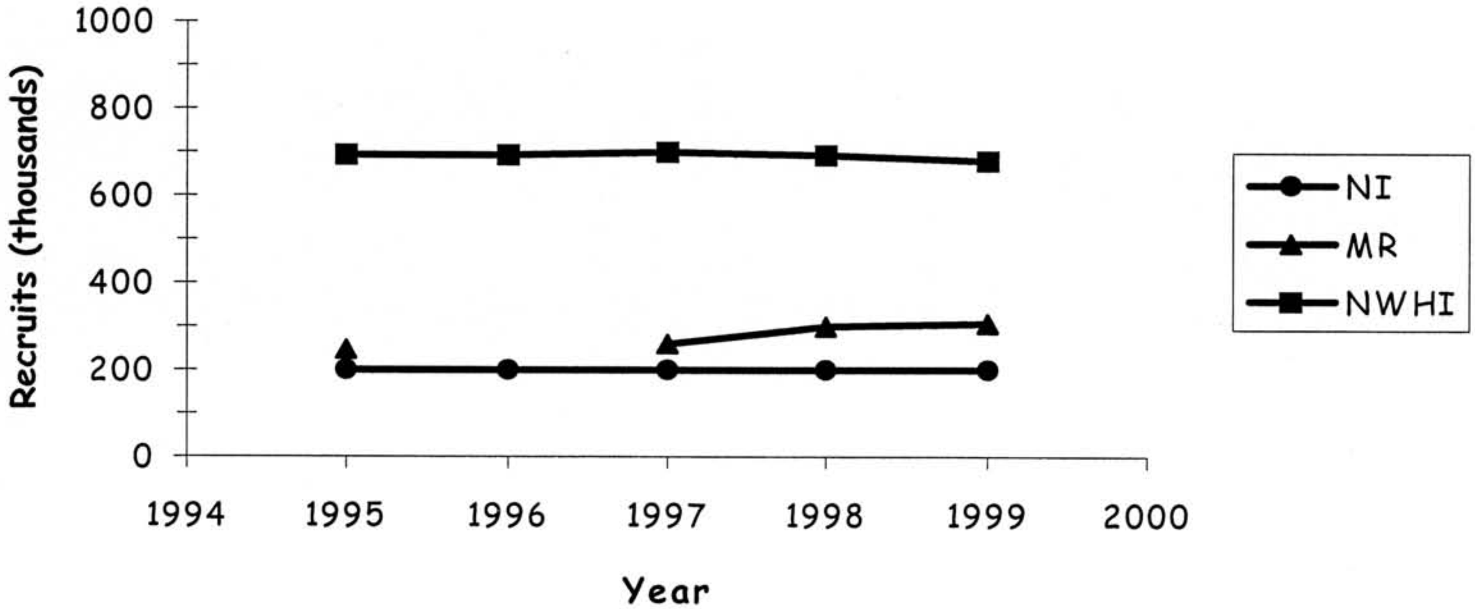

Figure 12. Model derived estimates of recruitment for Necker Island, Maro Reef, and the NWHI from 1995-99.

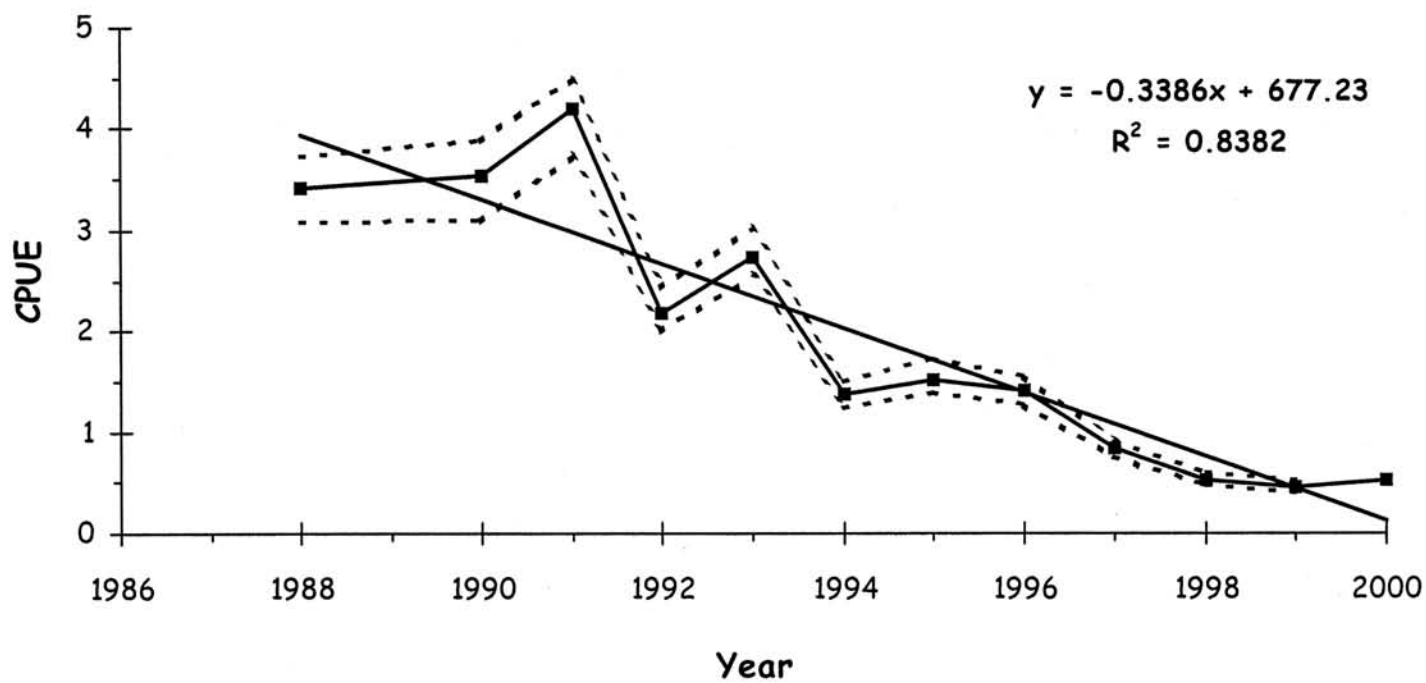

Figure 13. Research survey CPUE time series and 95% confidence interval of age 2 spiny lobster at Necker Island.

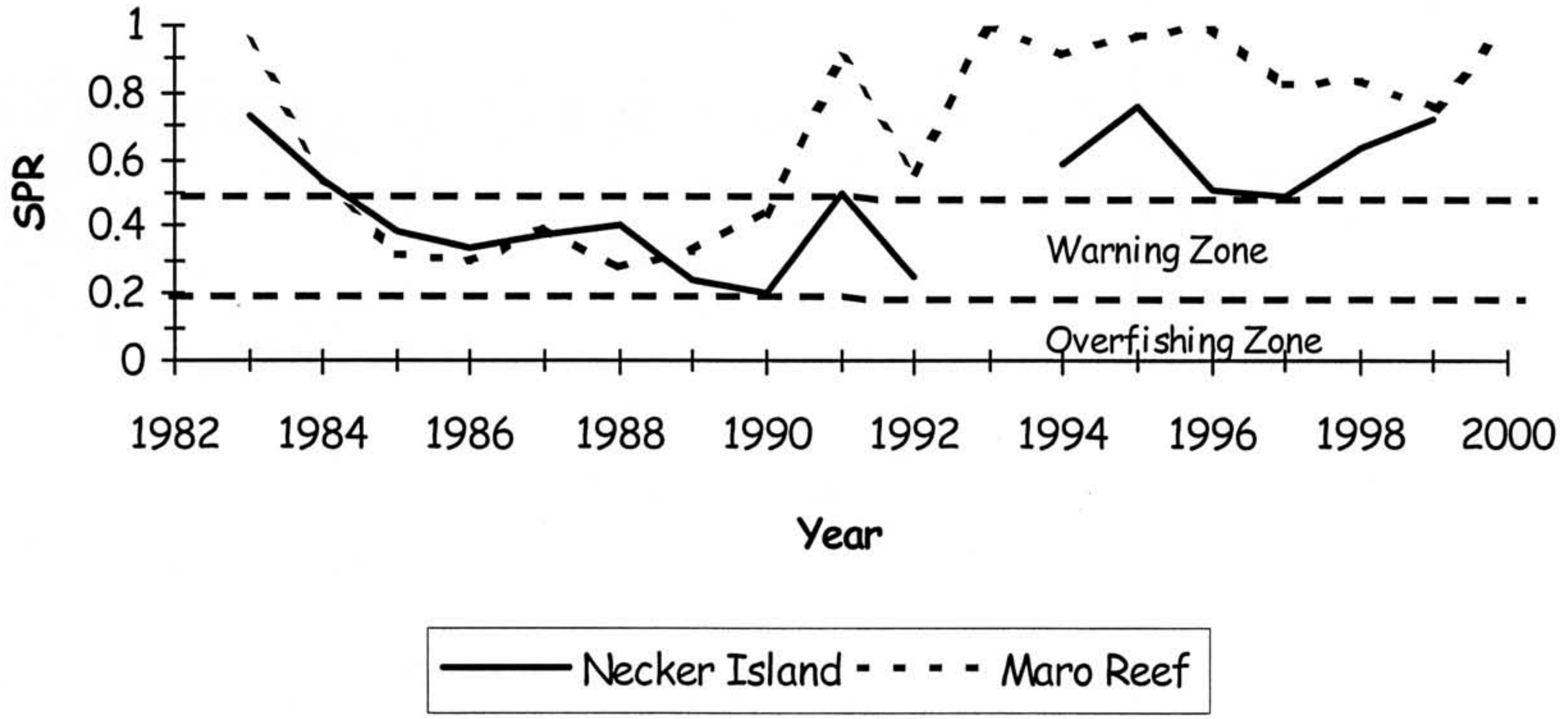

Figure 14. Metrics of the spawning potential ratio (SPR) for mature unberried lobsters from Necker Island and Maro Reef, 1983-2000. For each bank, SPR estimation uses the catchability coefficient described under scenario 2.

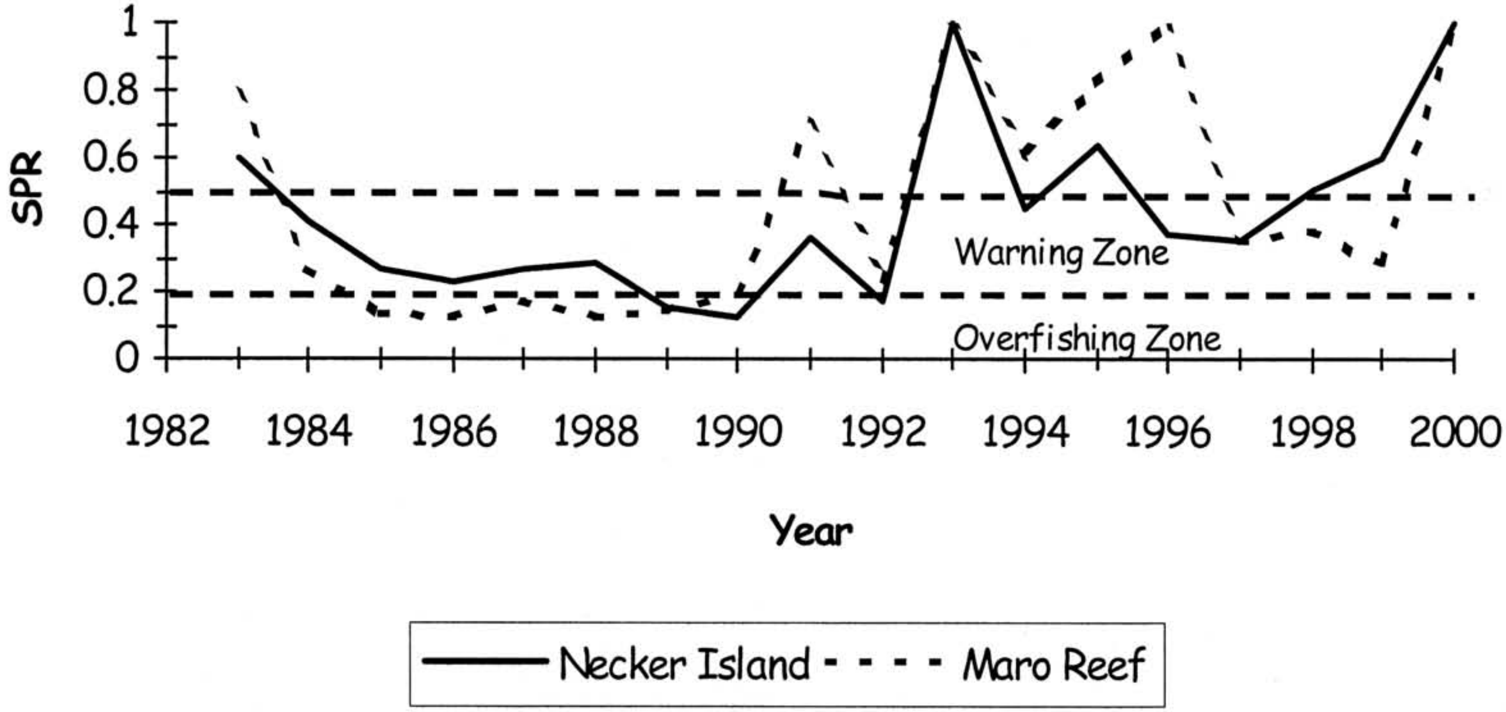

Figure 15. Metrics of the spawning potential ratio (SPR) for mature unberried lobsters from Necker Island and Maro Reef, 1983-2000. For each bank, SPR estimation uses the catchability coefficients described under scenario 1.

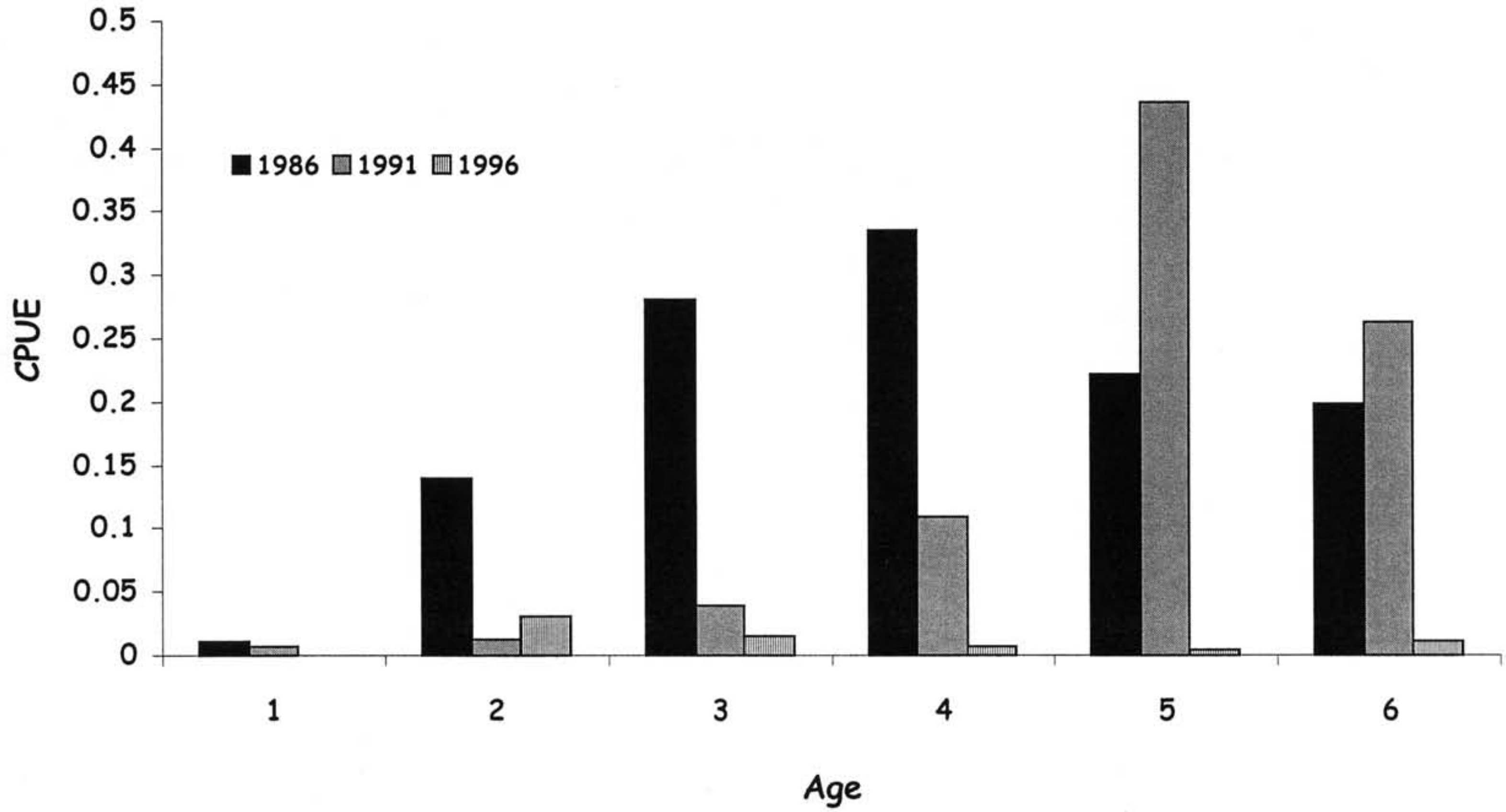

Figure 16. Age-specific spiny lobster research survey CPUEs from Laysan Island.